



Life Support and Habitation and Planetary Protection Workshop

Final Report

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Prepared for the Life Support and Habitation
and Planetary Protection Workshop
Held at the Center for Advanced Space Studies
Houston, Texas, April 27-29, 2005
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National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California

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PREFACE

Life Support and Habitation and Planetary Protection Workshop Final Report

A workshop entitled “Life Support and Habitation and Planetary Protection Workshop” was held in Houston, Texas on April 27-29, 2005 at the Center for Advanced Space Studies. The primary objective of the workshop was to facilitate the development of planetary protection guidelines for future human Mars exploration missions and to identify the potential effects of these guidelines on the design and selection of related human life support, extravehicular activity and monitoring and control systems. These specific topics were identified as needing further characterization during a previous workshop that broadly examined the need for planetary protection regulations for Mars human exploration missions (see NASA/CP – 2005-213461, 2005).

The concept of planetary protection was formally established in Article IX of the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space (UN, 1967). Planetary Protection (PP) is the term given to the practice of protecting solar system bodies (*i.e.*, planets, moons, comets, and asteroids) from contamination by Earth life, and protecting Earth from possible life forms that may be returned from other solar system bodies. PP is essential for several important reasons: to preserve our ability to study other worlds as they exist in their natural states; to avoid contamination that would obscure our ability to find life elsewhere—if it exists; and to ensure that we take prudent precautions to protect Earth's biosphere in case it does. NASA's Planetary Protection Office is responsible for the implementation of, and compliance with, appropriate PP policy for all US missions. In particular, NASA's Planetary Protection Officer is responsible for establishing detailed implementation requirements for specific mission types, depending on their potential impacts on specific celestial target bodies. While PP requirements for robotic missions exist, similar requirements for human missions to Mars have not yet been established. A major intent of this workshop was therefore to enable a coordinated and systematic means to assist the PP requirements generation process.

This workshop was sponsored by the former Life Support and Habitation (LSH) program, (the functions of which have now been incorporated into the Advanced Capabilities Division) in order to understand the potential influence of future PP policies on activities in the Advanced Life Support (ALS), Advanced Extravehicular Activity (AEVA) and Advanced Environmental Monitoring and Control (AEMC) programs. The ALS Program (now replaced by the Exploration Life Support (ELS) Program) provides life support technologies to support extended human presence in space. ALS systems are designed to significantly decrease life-cycle costs, reduce mass, volume, power and energy needs, improve operational performance, increase mass closure, and promote self-sufficiency. ALS technologies are designed to support the essential functions that sustain life including: controlling cabin pressure, temperature and humidity; decrease the need for supplied resources by regenerating air and water for safe use by humans; managing wastes; and supplying food, potentially from higher plant production. The AEMC Program is charged with providing mature, proven environmental testing technologies and control strategies to monitor the physical, chemical

and microbial environment of both the human compartments and the life support systems of current and future spacecraft environments and extravehicular activity. The AEVA Program is responsible for developing systems that provide reliable and safe mobile human life support, particularly suits and rovers for human extravehicular activity. The systems must be capable of providing thermal, atmospheric and humidity control and protection from the external environment.

Specialists from government, private industry and academia participated in the workshop. A plenary session was provided during the morning of the first day that addressed various areas of the workshop focus, namely PP, ALS, AEVA, and AEMC. For additional background, presentations were also given regarding robotic and *in-situ* resource utilization (ISRU) activities. In the afternoon, the participants were divided into two parallel groups to initiate discussion on designated workshop topics as well as to identify other areas for further discussion. Group summary presentations were delivered on the morning of the second day. The participants were then divided into four specialized sub-groups to address the charges that were customized for each sub-group. The sub-groups consisted of PP, ALS, AEVA, and AEMC. On the morning of the third day, each sub-group presented their findings to the overall group, with ensuing discussion. Overall group findings were recorded and are compiled in this edited report.

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May, 2006

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1 EXECUTIVE SUMMARY

This workshop was designed to bring representatives of the Life Support and Habitation (LSH) Division from the Advanced Life Support (ALS), Advanced Extravehicular Activity (AEVA), and Advanced Environmental Monitoring and Control (AEMC) Programs together with experts from NASA's Planetary Protection (PP) Office to identify and discuss the interfaces between the LSH activities and PP policy generation and implementation. The workshop was structured to create an open exchange of information between all parties to promote an integrated understanding of the numerous areas involved, and to identify research and technology development (R&TD) and requirements generation needs.

The workshop participants were first given preliminary presentations in the related topic areas and then divided into two general breakout groups that served to initiate analysis of issues and familiarize participants with the various fields of expertise represented. Subsequently, participants were divided into four specialized breakout groups (ALS, AEVA, AEMC and PP) to address assigned topics specific to those disciplines. A central tenant of the workshop was that PP policies for human missions consist of three main foci: 1) Avoid forward contamination of Mars or interference with scientific exploration from terrestrially-associated microbial contaminants; 2) protect astronauts from harmful contamination from martian life forms; and 3) control back contamination from the spacecraft, astronauts and materials that are returned to Earth. To facilitate discussion, starting assumptions were drafted prior to the workshop, and were supplemented by participants during workshop deliberations. Key concepts and assumptions included:

- Like robotic missions, human missions will need to take a conservative approach and assume that martian life exists until proven otherwise.
- No human habitat or EVA system can be fully closed. Therefore missions carrying humans to Mars will inevitably contaminate the planet to some degree with terrestrial organisms and materials.
- The increased capabilities that human explorers can contribute to the astrobiological exploration of Mars (as opposed to robotic missions) will be greatly reduced if human-associated contamination is not controlled and understood. It is therefore essential to identify, characterize, minimize, and control contamination sources and pathways. It will be critical that every attempt be made to obtain evidence of past and/or present life on Mars well before human missions occur (NRC, 1992, 2005).
- Safeguarding the Earth from potential back contamination is the highest planetary protection priority in Mars exploration.
- Crew and hardware on Mars will inevitably be exposed to martian materials. To the maximum extent practicable, these exposures should be understood and controlled.
- To decrease the potential for back contamination and reduce mission costs, it is desirable to leave wastes and other contaminated materials on Mars upon mission completion.
- Principal mitigation techniques include physical control over release (*e.g.*, containment), possibly in conjunction with active processing (*e.g.*, sterilization) and/or passive exposure to martian adverse surface conditions to destroy life and biosignatures.

- Deliberations are to be focused primarily on initial human Mars exploration missions. PP issues associated with pre-delivered cargo and systems are not major considerations for this workshop.

The breakout groups identified relevant sources and pathways for both forward and back contamination. Significant amounts of wastes will originate from human life support and mobility systems (ALS and AEVA) that can be classified as forward contamination in both PP and scientific terms. All materials from the martian environment are considered to be potential sources of back contamination (*e.g.*, soil, airborne particulates). Forward and back contamination pathways include: leakage from habitat, airlocks and other vessels; egress/ingress of humans, materials and equipment; EVA operations; surface storage/disposal of wastes; gas venting (nominal and contingency); and thermal systems leakage. Unintentional discharges may occur via events such as equipment failures, micrometeorite impacts, and rapid depressurization events. Breakout groups then identified potential mitigation approaches, and current technology capabilities and needs. It was suggested to preliminarily adopt conservative (more stringent) requirements to ensure that needed capabilities are available to meet mission schedule.

There was general consensus among the participants regarding the need to establish requirements for both PP and scientific investigations early in the development cycle, as they significantly affect system design, technology trade options, development costs and possibly mission architecture. Of particular concern were the areas of discharge and disposal limits, backward contamination limits, and ISRU. It will be necessary to identify and define what will be regarded as contaminants by both PP and science communities. In addition, there is a clear need to develop a classification system of zones of biological, scientific, contamination and operational importance prior to and during human missions. Finally, data on protocols and systems used for quarantine of crew and hardware upon Earth return were identified as significant system drivers.

It was concluded, however, that it is currently impractical to provide quantitative PP guidelines, as PP requirements will evolve in the coming years in response to numerous factors (*e.g.*, rapid changes in scientific information about Mars from robotic missions). Instead, a tentative conceptual approach consistent with current PP requirements was proposed to preliminarily guide the assessment of AEVA, ALS, AEMC and other aspects of human missions. The approach asserts that human missions to Mars shall not affect or otherwise contaminate “special regions” of Mars¹, primarily through the use of cleaning operations and prudent landing site selection. It was also proposed that calculations based on this approach will determine the tolerable levels of contamination allowed for specific aspects of any particular human mission. Specific details of the approach are to be determined, but will involve close collaboration with the scientific community, and the evaluation of unavoidable levels of human-associated contaminants and their implications.

¹ “Special Regions” as currently defined in the COSPAR Planetary Protection Policy of October 2002 include regions within which terrestrial organisms are likely to propagate, or are interpreted to have a high potential for the existence of extant martian life forms. Currently applied to regions where liquid water is present or may occur.

To facilitate the process of developing a quantitative set of PP requirements, the ALS community addressed the need to further define initial material inventory, process products and by-products, release mechanisms associated with forward contamination, and the need to incorporate back contamination into system design. Likewise, the potential physical (chemical or biological) impacts that identified AEVA suit/portable life support system (PLSS) vent/leakage constituents would have in regard to forward contamination need to be characterized. Methods to assess the potential for forward and back contamination include physical testing, simulation and analysis. The AEMC sub-group focused on the need for detection standards, response time, and the difficult challenges of identifying organisms that represent back contamination.

Finally, it was noted that long duration lunar operations can provide a relevant test-bed for many mission technologies. Mission planners should address PP technology on the Moon in ways that feed forward to martian exploration, even though the actual PP levels required on the Moon are considerably less stringent than those anticipated for Mars. Current concerns about biological potential and life detection on Mars suggest that technologies and operations related to PP are likely to need special attention. In planning the long term design and operations strategies, it will be important to avoid pursuing two distinct and expensive technology pathways—one for the Moon and the other for Mars.

2 RECOMMENDATIONS

2.1 INTRODUCTION

The establishment of requirements for the future human Mars exploration missions is a highly complex and integrated process that requires coordination of numerous fields of mission planning and technology development. Because of the increased potential for past or present life on Mars as opposed to the Moon, and the potential for cross-contamination to harm both martian ecosystems (if present) and the Earth's biosphere, PP policies are expected to be more stringent than those employed in initial Apollo landing missions. Establishment of these PP requirements will not occur in isolation; instead it will require interaction with those areas that it regulates. ALS, AEVA and AEMC are R&TD programs that have been identified as major interfacing areas that require increased collaboration in this process. In particular, knowledge will be required of the potential contaminant generation and pathways, and the mitigation capabilities of existing and future hardware systems. Of principal concern are overall leakage, material discharge and disposal, required monitoring systems and limits, controlling back contamination, quarantine procedures and identifying methods for unplanned contamination events.

Summaries of the salient conclusions and recommendations of each program area are presented below. Detailed findings and recommendations of each specialized breakout group can be found in Section 6 of this report.

2.2 ADVANCED LIFE SUPPORT

The ALS Program develops hardware and systems that support humans in space, while trying to significantly minimize launch and life-cycle costs, improve performance, and minimize or eliminate the need for resupply for long-duration missions. A broad array of internal and external requirements is levied upon ALS systems. PP (external) requirements have the potential to significantly affect ALS system research and technology development. Requirements derived from scientific life detection programs on uses and releases of hydrocarbons or other chemical/materials may exert an equal or stronger impact. Overall, these requirements affect technology trade options and development costs. Development of PP and scientific requirements for human missions should be accelerated, especially in the areas of discharge and disposal limits, backward contamination limits, and ISRU, to facilitate R&TD selection and implementation. Employing best estimates of available PP, scientific and ALS requirements can be used to preliminarily guide ALS technology development. Employing conservative (stricter) requirements should be considered, as it yields technologies that possess increased functionality and mission applicability.

To support the development of PP and science requirements, the ALS community needs to identify their potential for forward contamination via further definition of initial material inventory, process products and release mechanisms. Likewise, it is necessary to identify critical ALS technology and requirements gaps. This can be facilitated by performing analyses of mission scenarios using various ALS technology suites to comply with predicted requirements early in the development process. It is imperative to maintain open

communication between the PP, scientific, AEVA, AEMC, ALS and other communities regarding advances in knowledge related to PP requirements and concerns. These systems operate in an integrated fashion, and require coordination for mission success.

2.3 ADVANCED EXTRAVEHICULAR ACTIVITY

The AEVA community is in need of realistic PP guidelines and requirements that are; a) tolerant of EVA hardware systems design feasibility limitations, b) have technical practicality, c) have minimum impact to mission planning and operations, d) have an architecture so as not to affect human functional performance capabilities, and e) are acceptable to both the PP and science communities. These guidelines and requirements will drive costs; the only way to reasonably mitigate these costs is to identify these guidelines and requirements early in the development cycle.

In general, the AEVA community has identified the gaseous constituents that vent from extravehicular mobility units (EMUs), but does not presently know what level of biological material is released during the course of normal operations. The AEVA community therefore recommends conducting human space suit chamber tests to determine biological and chemical signature characterizations generated by space suit system venting and leakage effluents using sample tracer elements or markers.

The PP community needs to develop a system of classification for Mars surface sites based on the level of scientific and other interests that will define “zones of operation”, perhaps ranging from “no human contact” to “unlimited contact”. Lastly, the PP community needs to empirically identify and determine what level of microbial spore density and chemical/organic constituents are allowable for EVA surface operations.

2.4 ADVANCED MONITORING AND CONTROL

The AEMC Program is responsible for developing methods and sensors to support a variety of measurement needs, and complementary process control systems. With respect to specifically supporting PP and science-based requirements, numerous needs were identified. Overall, increased capability is needed for the detection of forward contaminants via a more accurate microbial burden analysis. Current PP assay methods include only culturable bacterial spores, and do not identify viruses, prions, and eukaryotic cells. It was recommended that the monitoring capability for forward contamination be equal to or better than the current specification for a *Category IVa* non-life detection mission (NASA, NPR 8020.12C).

It was determined that biological and organic contaminant baseline levels will need to be identified regarding contamination resulting from the habitats, EVA suits and rovers, and surface operations. This requires the characterization of ALS and AEVA as contaminant sources. Requirements development for PP and life-detection sciences needs to be coordinated with AEMC and performed early in the development cycle. Of notable mention are the needs for both forward and back-contamination detection targets and levels, needed system response time, and required mitigation technologies.

2.5 PLANETARY PROTECTION

Although there is an absence of explicit PP policies and requirements for human missions to Mars at present, it is possible to outline a conceptual approach for both forward and back contamination controls that center on protection of special regions. This approach can provide preliminary guidelines for planners and designers of AEVA, ALS, and AEMC activities. Refinement of the approach and development of more specific guidelines will likely occur over time in response to information from R&D activities coupled with findings from the precursor robotic missions outlined in the Exploration Roadmap (refer to Figure 2 in Section 6.4.7).

PP requirements for human missions will undoubtedly be very different than those used during Apollo missions. Clearly, early and regular coordination between the PP, scientific, planning, engineering, operations and medical communities is needed to develop workable and effective designs for human operations on Mars. Coordination will bring numerous mutual advantages to the various programs such as identifying common needs for new technologies (*e.g.*, among planetary science exploration, human mission operations, and PP).

Finally, long duration operations on the Moon may provide a relevant test-bed for many mission technologies. Mission planners must address PP technology on the Moon in ways that feed forward to martian exploration, even though the actual PP levels required on the Moon are considerably less stringent than those for Mars. Current concerns about biological potential and life detection on Mars suggest that technologies and operations related to PP are likely to need special attention. In planning the long term design and operations strategies, it will be important to avoid going down two distinct and expensive technology pathways—one for the Moon and the other for Mars.

3. INTRODUCTION

3.1 MOTIVATION FOR THE WORKSHOP

As evidenced by both previous human lunar and Mars surface robotic missions, it is expected that PP guidelines will serve as a strong driver in the design and operation of human Mars exploration missions. In addition, scientific objectives such as the search for extraterrestrial life may also affect mission design. It is therefore necessary to promptly establish martian PP guidelines for human missions to facilitate the timely and economical design of compliant spacecraft and habitation systems.

This requires a thorough knowledge of potential forward and back contamination pathways and characteristics, and a current understanding of the biological potential of Mars. While numerous considerations are involved in PP policy development, key program areas that require investigation include: the Advanced Life Support (ALS) program, which is responsible for managing air, water and solid wastes, and providing food and thermal control; and Advanced Extra-Vehicular Activity (AEVA), which could result in forward and back contamination primarily via human and equipment ingress/egress operations. Additionally, the Advanced Monitoring and Environmental Control (AEMC) program will be responsible for developing methods that facilitate the monitoring of contaminants relevant to established PP and scientific guidelines.

This workshop was created to bring together representatives from ALS, AEVA, AEMC and PP communities to identify and address significant open design and operation issues regarding PP and the human exploration of Mars, and to initiate the generation of preliminary PP guidelines to facilitate system development.

3.2 CHARTER TO THE WORKSHOP

The establishment of system requirements is an urgent need for the ALS, AEVA and AEMC programs. This workshop was therefore designed to identify and systematically address the process of requirements generation with respect to PP concerns in relation to these programs. In this vein, workshop participants were charged to address the following top-level workshop objectives:

- 1) Initiate communication, understanding, and a working relationship between the ALS, AEVA, AEMC and PP communities regarding the effect of PP policy development and implementation requirements for future human missions.
- 2) Define top-level PP concerns and issues associated with both forward and back contamination, and determine their likely effects on ALS, AEVA and AEMC hardware and operations for the first human mission to Mars.
- 3) Identify PP requirements that will be needed to guide future technology development for ALS, AEVA and AEMC systems in advance of the first human mission.

4) Examine management approaches that may be used to reduce the risk of developing ALS, AEVA and AEMC systems prior to full definition of PP policies.

5) Identify important research areas and identify any gaps in science or technology capability that will help guide the development of technologies and approaches for ALS, AEVA, and AEMC consistent with PP concerns regarding both forward and back contamination.

4 WORKSHOP PLANNING

4.1 WORKSHOP PLANNING AND DEVELOPMENT OF PRE-WORKSHOP DOCUMENTS

The organizing committee consisted of representatives from the Advanced Life Support Program, NASA Headquarters, SETI Institute and the Planetary Protection Office. Numerous teleconferences were conducted among the committee members prior to the workshop to develop the purpose and scope of the workshop, and produce the background readings for participants. Additionally, various workshop participants conducted telecons to generate a preliminary set of Workshop Assumptions to provide a well defined starting point for deliberations. Additional assumptions were generated during the workshop.

To better prepare the participants for performing workshop tasks, several documents were compiled and given to the participants as reading material prior to the workshop. The documents are listed below.

- Draft Working Copy of: Life Support and Habitation and Planetary Protection Workshop Assumptions (See Section 5.3.1 for the actual assumption list and accompanying participant comments)
- Summary of: Safe on Mars: Precursor Measurements Necessary to Support Human Operations on the Martian Surface. NRC Committee on Precursor Measurements Necessary to Support Human Operation on the Surface of Mars, National Academy Press, Washington DC, 2002
- Summary of: Planetary Protection Issues in the Human Exploration of Mars (Summarized) Race, M.S., M.E. Criswell, and J.D. Rummel, 2003. (Paper no. 2003-01-2523. International Conference on Environmental Systems (ICES), Vancouver, B.C. July 2003)
- Summary of: Influence of Planetary Protection Guidelines on Waste Management Operations. J.A. Hogan, J.W. Fisher, J.A. Levri, M.S. Race, K. Wignarajah, P. Stabekis. International Conference on Environmental Systems (ICES), Rome, Italy. July 2005, Paper no. 2005-01-3097.

Additionally, relevant programmatic websites were given to allow participants to seek additional information. These website are listed below:

Life Support and Habitation: <http://lsh.jsc.nasa.gov/>

Life Support and Habitation Overview Presentation:
<http://www.dsls.usra.edu/meetings/bio2005/pdf/Walzpresentation.pdf>

Planetary Protection: <http://planetaryprotection.nasa.gov/pp/documents/index.htm>

Advanced Life Support: <http://advlifesupport.jsc.nasa.gov/>

Advanced Monitoring and Environmental Control: <http://aemc.jpl.nasa.gov/>

Advanced Extravehicular Activity: <http://ctsd.jsc.nasa.gov/ec5/advanced.html>

4.2 PARTICIPANTS

Participants were selected to assemble a diverse set of programmatic managers, biological and physico-chemical researchers, systems analysts, engineers and technology developers from Planetary Protection, Advanced Life Support, Advanced Extravehicular Activity, Advanced Environmental Monitoring and Control, *In-Situ* Resource Utilization and Robotics programs. Participants from federal government, private companies and academia were invited. A major intent was to assemble a broad array of expertise that promoted both a top-down and bottom-up examination of the various topics. It was a major goal of this workshop to initiate communication and create long-standing collaborative relationships between necessary personnel. Refer to Appendix B for the full list of participants

4.3 WORKSHOP STRUCTURE AND LOGISTICS

4.3.1 Invited Speakers

The workshop was initiated with a series of speakers that addressed the specific issues of their respective program areas. The speakers presented tutorials that served to educate the general audience regarding the various facets of ALS, AEVA, AEMC and PP and their potential interfaces. Presenters were briefed prior to the workshop as to the general topic areas to address. Invited talks are listed below.

- **Advanced Life Support** – Dr. Daniel J. Barta, NASA Johnson Space Center
- **Advanced Extravehicular Activity** – Dr. Lara Kearney, NASA Johnson Space Center
- **Advanced Environmental Monitoring and Control** – Dr. Darrell Jan, Jet Propulsion Laboratory
- **Planetary Protection and its Development** – Dr. John D. Rummel, NASA Headquarters
- **Planetary Protection Implementation on Robotic Missions** – Dr. Karen Buxbaum and Dr. Jack Barengoltz, Jet Propulsion Laboratory
- **Planetary Protection and Humans on Mars** – Report of the First Workshop – Dr. Margaret S. Race, SETI Institute

4.3.2 Breakout Groups

After the presentations, workshop participants were divided into two parallel General Breakout Groups that separately addressed pre-determined topics. They likewise identified and discussed other issues regarding overall ALS, AEVA, AEMC and PP concerns. The purpose of the General Breakout Groups was to provide an open forum where all participants could discuss issues within the various fields of expertise, thereby preparing themselves for more specific tasks associated with the Specialized Breakout Groups. Two separate

presentations were then delivered to all participants that conveyed the group findings, followed by a general discussion.

The participants were then separated into Specialized Breakout Groups to further elaborate on assigned topics and generate a final presentation that summarized the issues within their breakout focus. The Specialized Breakout Groups consisted of ALS, AEVA and AEMC, and PP. Each Specialized Breakout Group prepared a presentation that was presented in a plenary session on the morning of Day 3. These presentations were followed by a general discussion and workshop conclusions.

A set of pre-determined topics and questions for the two general and four specialized breakout groups were developed and reviewed prior to the workshop. These were compiled into electronic presentation format to facilitate the generation of both summary presentations and the information required for the final report. Specialized Break-out Group leaders were responsible for summarizing the groups' findings, and preparing their sections for the final report. The assignments and discussions topics for the various breakout groups are summarized below:

The purpose of the two **General Breakout Groups** was to provide a means to allow participants to openly converse within a group that contained expertise from all the workshop focus areas. Having two separate groups allowed for separate approaches to be pursued, and provided a manageable group size. The charge to the General Breakout Groups was to focus on top-level PP concerns and issues likely to impact various specific systems for human missions to Mars.

The **ALS Specialized Breakout Group** was required to identify issues that could interface with PP within the seven program elements, namely: Waste Management, Water Recovery, Air Recovery, Food Systems, Thermal Control, Biomass Production and System Integration Modeling and Analysis.

The **AEVA Specialized Breakout Group** was responsible for examining the influences of PP issues on the task of providing humans with portable life support systems and vehicular mobility.

The primary task of the **AEMC Specialized Breakout Group** was to identify and address the monitoring and control needs of human missions to Mars in relation to potential PP regulations.

The **PP Specialized Breakout Group** differed from the groups in that a primary function of deliberations was to devise a preliminary approach capable of guiding ALS, AEVA and AEMC programs regarding system development in relation to PP regulations, as well as to provide a framework that establishes a method for subsequent requirements development.

4.3.3 Workshop Assumptions

A set of working assumptions was developed prior to the workshop in order to give participants well defined boundaries on the topics of consideration. These assumptions are listed below.

- 1. Human Mars missions will necessarily generate materials originating from both biotic and abiotic sources that could potentially contaminate Mars and/or be classified as an indicator of life.*
- 2. The first human mission to Mars is not likely to occur before ~2030, and extensive data and information from precursor robotic science missions will help guide the selection of the landing site and will provide sufficient knowledge about martian environmental materials to support appropriate design of human missions and systems.*
- 3. Multiple Mars human exploration mission architectures may be utilized, including an on-orbit (non-landing) mission and short and/or extended duration surface stays (e.g., 30 to >600 days).*
- 4. Multiple human missions to the Mars surface may occur over the course of years, either to a common landing site or to multiple landing sites. If to a common site, the common site habitat may be reoccupied, and operate at a TBD level during periods between crew stays.*
- 5. A split mission strategy may deploy some mission assets at Mars prior to the launch or landing of the crew. Thus, prior to the arrival of humans on Mars, precursor robotic missions may have delivered and cached cargo and materials including essential hardware and supplies for establishing the first base camp.*
- 6. There may be autonomous deployment of critical surface system elements prior to human arrival, potentially including: science equipment, habitat, unfueled ascent vehicle, and ISRU fuel production, power, thermal control, navigation, communication and transit/mobility systems.*
- 7. Any hardware or materials delivered to Mars by precursor robotic missions are presumed to have complied with the appropriate forward contamination controls prior to arrival. This workshop will focus only on the Planetary Protection (PP) impacts of the materials or hardware during their use in operations and activities associated with human missions.*
- 8. The autonomous deployment of surface system elements prior to human arrival may generate materials that have PP concerns (e.g., associated with construction, excavation, trenching, road building, installation of navigation and communication systems, breathing gas, water, etc.).*
- 9. The design of human and equipment ingress/egress protocols and associated infrastructure will be established to control human contact with the martian environment. This includes the handling of both reusable and expendable (waste) materials.*

10. Planetary protection concerns for a human mission will have three foci (as outlined in the Pingree Park report (Race et al. 2003): a) avoid forward contamination of Mars or interference with scientific exploration from terrestrially-associated microbial contaminants; b) protect astronauts from cross contamination or contact with martian materials, whether inside or outside the habitat; and c) break the contact chain with Mars and avoid or minimize back contamination from the spacecraft, astronauts and materials returned to Earth.

11. Human Mars surface missions will likely involve human exploration and operations outside of the habitat vessel, requiring human egress/ingress. Extravehicular activity (EVA) may range from local to extensive excursions. The crew will likely utilize personal EVA suits, and may be aided by motorized rovers.

12. High cost penalties associated with the propulsion of large amounts of waste materials, along with crew health and safety, are strong incentives to allow waste materials to remain on Mars after mission completion. For similar reasons, controlled jettisoning of transit segment wastes into interplanetary space may also be desirable.

13. Materials that are jettisoned to space or remain on Mars after mission completion must be managed to avoid forward and back contamination as prescribed by Planetary Protection guidelines (to be established).

14. No assumptions are made at this time about quarantine requirements or facilities (or health stabilization facilities and requirements) upon return from Mars.

5 COMBINED REPORT OF GENERAL BREAKOUT GROUPS

5.1 GENERAL BREAKOUT GROUP PARTICIPANTS

General Breakout Group 1

LSH Lead: Mark Kliss

PP Lead: Margaret Race

Group Members:

Carlton Allen

Karen Buxbaum

Paul Campbell

Max Coleman

Louise Hamlin

Anthony Hanford

John Hogan

Joseph Kosmo

Michael Lawson

Aaron Mills

Richard Sauer

Laurent Sibille

Frederick Smith

Kasthuri Venkateswaran

Carl Walz

Chantel Whatley

General Breakout Group 2

LSH Lead: Dan Barta ALS

PP Lead: Perry Stabekis

Group Members:

Judy Allton

Jack Barengoltz

Joe Chambliss

Sharon Cobb

Alan Drysdale

Dean Eppler

John Fisher

Darrell Jan

Charlie (Mark) Ott

Alan Perka

John Rummel

5.2 CHARGE TO GENERAL BREAKOUT GROUPS (CHARGE APPLIES TO BOTH GROUPS)

Pivotal Focus:

Focusing on both forward and back contamination, define the top-level PP concerns and issues that are likely to impact specific systems for human missions to Mars.

Possible specific issues for inquiry:

- Initiate general discussion using the Specific Questions List (see section 5.3.2) to promote interchange between the various fields of expertise.
- Identify potential forward and back contaminants, pathways and interfaces for ALS and AEVA systems and relevant AEMC monitoring needs.

- Identify PP requirements/issues that require further definition.
- Identify gaps and prioritize discussion topics and issues listed in the Specialized Breakout Group tasks.

5.3 GENERAL FINDINGS AND RECOMMENDATIONS

Having two separate groups allowed for separate approaches to be pursued, and provided a manageable group size. Because there was significant overlap between the responses of the two groups, the following is a unified summary (with minimal editing) of the findings from both General Groups. Topics that are captured in greater detail in the Specialized Group reports are deemphasized here.

5.3.1 Review and Discussion of Workshop Assumptions

Task: Workshop participants were provided set of 14 initial assumptions to assist in guiding deliberations. Participants found it helpful to address each assumption and provide comments for possible revisions and additions. The initial assumptions are numbered and in bold italics, followed by group comments (when presented):

1. Human Mars missions will necessarily generate materials originating from both biotic and abiotic sources that could potentially contaminate Mars and/or be classified as an indicator of life.

Even with the best of designs, no habitation system will be fully closed, even if only because of unavoidable leakage of gases. Numerous potential pathways were identified for both forward and back contamination (*e.g.*, ingress/egress and EVA operations), indicating that forward and habitat contamination will occur. Dustlocks for crew and material transfer were proposed as a potential means to control back contamination.

Initially, forward contaminants will be of local concern, but global and long-term scales need to be considered. There will likely be different time and distribution scales for different contaminants. Wind is probably the most prominent mechanism for spreading contaminants both in the short and long-term. Subsurface aquifer transport or dispersion is less understood, and should be further examined due to the potential for microbial proliferation and persistence.

The materials used in ALS and other systems need to be identified and monitored (*e.g.*, organic inventory). It is advisable to avoid generation of undesirable by-products or wastes through design and advanced planning. While it was felt that non-condensable gases could likely be vented to martian environment, provided they are filtered to capture viable organisms, further research on gas venting is recommended. It is assumed that contamination controls will be levied on the mission, but it's uncertain how forward contamination controls would apply to the inside of a spacecraft on human missions; mitigation appears to be the only practical approach. It was also recommended that martian dust undergo thorough characterization in advance of human missions to understand its potential for back contamination and general nuisance properties.

Definition is required as to what will be considered a contaminant, for both PP and life detection science. Likewise, limits needed for detection will aid in the establishment of release levels. Because of the potential challenges in identifying putative martian life, it was proposed that martian dust could serve as a surrogate for back contamination monitoring.

2. The first human mission to Mars is not likely to occur before ~2030, and extensive data and information from precursor robotic science missions will help guide the selection of the landing site and will provide sufficient knowledge about martian environmental materials to support appropriate design of human missions and systems.

Robotic missions may help guide the missions, but will not fully retire all the risks. The current robotic program will provide important information, but preliminary design decisions will need to be made before all necessary information is available. This reveals the challenges of planning in the face of uncertainty.

The phrase “sufficient knowledge” suggests that enough information will be provided for the “appropriate design.” It is recommended that the word “sufficient” be deleted and that discussions be conducted during this workshop to define requirements for precursor missions. The Mars Exploration Program Assessment Group (MEPAG) may be addressing both PP and Science questions.

3. Multiple Mars human exploration mission architectures may be utilized, including an on-orbit (non-landing) mission and short and/or extended duration surface stays (e.g., 30 to >600 days).

Orbiting non-landing spacecraft can be a PP concern if materials are released due to venting or other release failures, collision with meteoroid or debris or if it de-orbits.

4. Multiple human missions to the Mars surface may occur over the course of years, either to a common landing site or to multiple landing sites. If to a common site, the common site habitat may be reoccupied, and operate at a TBD level during periods between crew stays.

5. A split mission strategy may deploy some mission assets at Mars prior to the launch or landing of the crew. Thus, prior to the arrival of humans on Mars, precursor robotic missions may have delivered and cached cargo and materials including essential hardware and supplies for establishing the first base camp.

Precursor un-manned spacecraft associated with human missions may deploy either on surface or in orbit (supplies, storage, return vehicles).

6. There may be autonomous deployment of critical surface system elements prior to human arrival, potentially including: science equipment, habitat, unfueled ascent vehicle, and ISRU fuel production, power, thermal control, navigation, communication and transit/mobility systems.

It would be prudent to rephrase to include “ISRU production for fuel and life support”.

7. Any hardware or materials delivered to Mars by precursor robotic missions are presumed to have complied with the appropriate forward contamination controls prior to arrival. This workshop will focus only on the Planetary Protection (PP) impacts of the materials or hardware during their use in operations and activities associated with human missions.

8. The autonomous deployment of surface system elements prior to human arrival may generate materials that have PP concerns (e.g., associated with construction, excavation, trenching, road building, installation of navigation and communication systems, breathing gas, water, etc.).

9. The design of human and equipment ingress/egress protocols and associated infrastructure will be established to control human contact with the martian environment. This includes the handling of both reusable and expendable (waste) materials.

Participants agreed that some level of forward and back contamination will occur through egress/ingress operations. Therefore, there was strong recognition of the importance of developing a system of classifying zones of biological, scientific, contamination and operational importance prior to and during human surface missions. Like robotic missions, human missions will need to take a conservative approach and assume that martian life exists until proven otherwise. Additionally, it was agreed that leaving wastes and other contaminated materials on Mars after mission completion was an effective method of decreasing back contamination, provided that materials are appropriately managed.

10. Planetary protection concerns for a human mission will have three foci (as outlined in the Pingree Park report (Race et al. 2003) : a) avoid forward contamination of Mars or interference with scientific exploration from terrestrially-associated microbial contaminants; b) protect astronauts from cross contamination or contact with martian materials, whether inside or outside the habitat; and c) break the contact chain with Mars and avoid or minimize back contamination from the spacecraft, astronauts and materials returned to Earth.

11. Human Mars surface missions will likely involve human exploration and operations outside of the habitat vessel, requiring human egress/ingress. Extravehicular activity (EVA) may range from local to extensive excursions. The crew will likely utilize personal EVA suits, and may be aided by motorized rovers.

EVA suits are proven to be inherently leaky; at least 50 leakage pathways have been identified aside from the porosity of suit materials themselves. Forward and back contamination is foreseen as inevitable. The analogous approach of sealing electronic boxes with HEPA filters (an approach used for robotic missions) is not tenable for humans. Additionally, suits will need repair, maintenance and cleaning on a scheduled

basis. Methods need to be instituted to manage human exposure to martian dust. Likewise, microbial bioburden (*i.e.*, microbial load) standards are required for EVA suits.

12. High cost penalties associated with the propulsion of large amounts of waste materials, along with crew health and safety, are strong incentives to allow waste materials to remain on Mars after mission completion. For similar reasons, controlled jettisoning of transit segment wastes into interplanetary space may also be desirable.

There are three main mitigation approaches for risk management of wastes: 1) physical control over release (*e.g.*, containment in canisters), 2) active destruction or transformation of the material (*e.g.*, desiccation, oxidation, sterilization), and 3) passive use of adverse surface environments for sterilization or destruction of biosignatures. Existing technologies may not be adequate to support all Mars waste (solid, liquid, gases) management needs. The current approach for human spaceflight focuses on either store and return, or jettison.

Currently, an explicit policy regarding waste jettison in deep space is lacking. While operationally it has been performed, further research is required. In general, it was felt that disposing waste materials in deep space may be considered as an acceptable option. Any wastes left on the surface must be contained at a TBD level, with special attention given to recycling, reuse or future reversibility on a TBD time scale. It is possible that this interim approach to the disposal of wastes may be sufficient to meet PP constraints.

13. Materials that are jettisoned to space or remain on Mars after mission completion must be managed to avoid forward and back contamination as prescribed by Planetary Protection guidelines (to be established).

Clarification is required to distinguish between “jettisoned” (suggesting a passive release that continues to travel with the spacecraft) and an “active jettison” which suggests a propulsion system associated with the release. Another method of jettison would involve a release prior to course correction. Further discussions are needed on whether a contained jettison is feasible when relying on atmospheric incineration in the martian atmosphere. If not, would this incineration be possible for liquid and gas release? Conventional wisdom indicates that breakup is related to speed, trajectory, size, type of material, etc. Small particles may get to the surface with minimal heating. The current PP specification for flash sterilization is 500°C for ½ second, for atmospheric entry (NASA, NPR 8020.12C). However, additional research is clearly warranted regarding microbial survival and incineration (*e.g.*, Nematodes on shuttle Columbia survived the re-entry breakup).

Questions of microbial survival and radiation will need further study as well. The UV radiation environment in orbit and at the surface may have a sterilizing effect. For small particles in the atmosphere, what contact time/dose may be adequate? The NASA PP requirements and guidelines for robotic spacecraft (NASA, NPR 8020.12C) includes a specification concerning UV radiation exposure, but this regards transit. There is no UV

lethality specification for Mars upper atmosphere that specifies the D value (the number of orders of magnitudes of kill).

14. No assumptions are made at this time about quarantine requirements or facilities (or health stabilization facilities and requirements) upon return from Mars.

This statement is ambiguous and unclear. If no assumptions are made, can the working group define the quarantine requirements and facilities? For most of the discussion, the group assumed the quarantine requirements and facilities would promote acceptable PP. Details about quarantine requirements are TBD and will necessarily involve medical and other experts.

Suggested Additional Assumptions:

The Moon would be utilized as a test bed to study Mars PP.

What can be accomplished regarding using the Moon as a test bed is an open question, particularly since the PP requirements for Mars are stricter than for the Moon, where conditions are not conducive for microbial survival or life.

We may not be able to discern between Earth life and Mars life.

This is an extension to the discussions of assumptions 1 (Earth contamination confuses search for life on Mars) and 14 (sickness due to Earth-based human illness or infection from Mars organism).

General Observation:

Many of the assumptions are more applicable to longer duration missions, though the early Mars missions may be of shorter duration. The strategy of the working group was general and not duration dependent.

5.3.2 Discussion of Specific Questions List

A list of pre-determined questions was given to the participants in the two general breakout groups to ensure that key areas were discussed. (***NOTE: the responses below to these pre-determined questions reflect the participants' discussions and are not intended to serve as formal recommendations.***)

Q1. Will interplanetary disposal during transit be allowed, and what conditions will be imposed?

As mentioned in earlier comments (see assumptions), passive jettison will result in material staying with spacecraft and continuing to Mars. The use of a more active system or modifications to trajectory to enable passive jettison for disposal are possible, though either would increase costs. The use of any alternative must have no substantial risk toward the contamination of Mars.

Q2. Will any waste be allowed to be stored or disposed of on/below the surface if adequately contained? If so, what level of containment would be sufficient? What would be the necessary characteristics of the waste? How long will containment need to be assured? What level of certainty is required (e.g., <10⁻⁴)? Does the state of the waste need to be rendered so as to preclude serving as a substrate for biological growth (i.e., mineralized)? Will wastes be allowed to remain in the surface habitat after mission completion (or do they need to be contained on the surface or returned home)?

If containment is adequate, waste can be stored on the surface of Mars. Conditions or requirements including pressure constraints, venting options (including filter size and materials) will need to be defined. The acceptable release concentration could be defined by comparing it to current robotic mission requirements. If waste containers were stored below the surface, the container may have greater protection. In contrast, rupture of the container below ground may increase the potential for successful invasion of any existing martian ecosystems with terrestrial life. Processing to stabilize and/or sterilize wastes should be considered before the waste container is sealed. Additionally, the physical/chemical characteristics of the solid waste will have a direct effect on the life expectancy of the container. If habitats are not to be reused after a mission, they may be appropriate waste disposal sites, as it would offer another layer of protection. Likewise, they are easily located in case waste retrieval is necessary.

Q3. Will there be constraints as to what will be allowed to be returned to Earth (i.e., potential for back-contamination)? The inside of the returning spacecraft may be contaminated to some degree from EVA interchange. This material will enter the solid, liquid and gas streams through various means. Therefore, how do we return home?

Yes, there will be constraints on material returned to Earth, so requirements are necessary to preclude contamination of the crew and habitat, especially in regard to EVA. Suits and tools should not enter the habitat, so a mechanism may need to be developed crew to safely remove suits before entering the habitat. In addition, an area may be necessary for suit maintenance (e.g., disposable suit “garage”). The quarantine procedure and facility are undefined and directly affect this question. The use of Earth-based models for quarantine, such as those developed by the Center for Disease Control (though they may not provide all necessary answers), may guide the development of cleaning procedures and isolation of returned samples (see, Rummel *et al.*, 2002). For the crew as well as PP, external and internal contamination is an issue. The goal of zero contaminants entering the vehicle (as initially advocated by the Pingree Park workshop – see Criswell *et al.*, 2005) is admirable, though impractical. Development of requirements will require additional detailed discussion including the limitation of ‘hitchhiker’ contamination and how this philosophy should be incorporated into the design of the vehicle/habitat. Areas included in the design/trade studies should include evaluation of cross-contamination after an EVA and docking activities with Earth return vehicles.

Q4. Determine how internal habitat ALS technologies might affect the potential for planetary surface contamination (e.g., increased bioloads on suits and equipment, venting gases/liquids/particulates to planetary atmosphere via airlocks, etc.)

- *How "clean" do we need to be inside in order to support external PP requirements? Will the ALS Program be involved with cleaning issues, or will a different program be tasked with that? Will ALS need to handle cleaning by-products?*
- *Are there special measures that should be taken to avoid the propagation of extraterrestrial organisms in ALS systems? For example, if waste is stored "as-is", the waste could serve as a growth medium (if contaminated). The same is true for biological processors for waste, water and air.*
- *What extent of gas venting (from habitats) will be allowed? What compounds will be allowed/excluded? Will particulate (microbial, organic, inorganic) control be necessary?*

Internal cabin materials can be released both through airlock or cabin leakage. Therefore, internal cleanliness will affect the extent and character of this contamination. As a first attempt, one suggestion was to make calculations by analysis and compare against 3×10^5 spores, which is the current requirement for robotic missions. Vents should be HEPA filtered to remove microorganisms (see specifications in NPR 8020.12C). The need to remove biosignature gases and other materials will be determined by life detection science constraints. Data can be generated based on analysis and presented to scientists for review. Space craft material off-gassing is of concern on the outside of spacecraft, including seals and lubricants as possible sources.

Further definition of terms is required to accurately answer some questions. In particular, is there a standard definition of a "biosignature"? Are all volatile organics considered biosignatures? The scientific community should be tasked to define this and other terms. It therefore may be acceptable to release Volatile Organic Compounds (VOCs), depending on definitions and scientific sensitivities.

Operational measures for cleaning will clearly need to be developed. Existing hygiene procedures, such as Hazard Analysis and Critical Control Point (HACCP) analyses, may be first line of defense (aside from contamination prevention) and may be adequate. Contingency kits/protocols for common contingencies may need to be employed.

Q5. Determine similar restrictions and requirements to be placed on human extravehicular activity (EVA) systems

EVA suits will likely have similar restrictions and requirements as habitats and other vehicles. Venting of gas may not be allowable if only treated with a HEPA filter. Requirements need to be established regarding allowable chemical/microbial leakage.

Q6. Determine restrictions and/or required procedures to be emplaced for human activities and systems for use outside the habitat, particularly with respect to:

- *Subsurface access*
- *Use and/or distribution of fluids outside the habitat*
- *Planned or unplanned biological experiments or releases*

As the subsurface may be a suitable environment for microbial growth, this area can be considered a “hot spot” and potential cross-contamination requirements should be more stringent. Sub-surface access should be conducted using only sterile equipment, maintaining a clear separation between the operator and drilling equipment. Questions remain on how to define the interface/depth/definition between subsurface and surface environments.

Most fluids that are used will need to be completely contained. In the event a fluid is required outside of containment, such as for construction, the use of local water (Mars ice) is acceptable, though it should not be contaminated from terrestrial sources. Fluids for drilling would have to be sterile. Options for these fluids may include blown-in foams or two-part cements.

Planned biological experiments would likely need several layers of containment. A list of biosignatures would be beneficial for design and implementation of the habitat.

Q7. Determine what types of monitoring systems, procedures and equipment are necessary to assist in PP policy implementation and verification of compliance. This includes issues regarding contamination of the planetary surface, habitat contamination and return of spacecraft and samples to Earth.

The characteristics of martian microorganisms, if they exist, are unknown. Therefore the closest analog would be to attempt to detect markers/organisms of terrestrial origin. As monitoring systems could possibly be used to detect both terrestrial and martian microorganisms/chemical agents, they should be located near the airlocks, around storage areas, and at sites located at selected distances away from habitat to detect propagation of contaminants. Additional monitoring units for dust could also be useful for the detection of potential back contamination. The crew must be adequately trained in PP and contamination control regardless of the type of monitoring equipment used. It was suggested that at least one of the crew members be trained and be responsible for PP compliance.

For forward contamination, monitoring systems could be employed to detect leaks, but it is questionable whether this would be valuable. The use of biological sensors is worthy of examination. For backward contamination, the major challenge is the lack of knowledge of target contaminants. It is possible to utilize martian dust monitors to serve as a representation of the potential for back contamination. Experiments that challenge Earth organisms with simulated Mars environmental conditions should be conducted.

5.3.3 Interface Identification

General Groups were also asked to focus on both forward and back contamination to identify and discuss interfaces between ALS, AEVA, AEMC and PP and potential consequences for human missions to Mars.

Participants were requested to perform the following tasks:

- Initiate general discussion using the Specific Questions List to promote interchange between the various fields of expertise
- Identify potential forward and back contaminants, pathways and interfaces for ALS and AEVA systems and relevant AEMC monitoring needs
- Identify PP requirements/issues that require further definition

General Findings:

- ALS and AEVA are very similar systems and both will utilize AEMC for monitoring.
- Common consumables and wastes are utilized for ALS and AEVA. Likewise, they may be transferred from common supplies and waste tanks.
- Pressurized rovers are essentially mobile habitats, though it is anticipated they will have higher leakage rates. Rovers may be less constrained with respect to PP requirements as they will be left on Mars, and the crew may wear protective suits while inside. If both suits and rovers dock with the habitat, a higher level of cleanliness can be maintained. Further investigation is required regarding the development of docking systems for both suits and rovers.

Other suggested topics for further discussions included the following:

- Identification of implications of promising new technologies and approaches prior to first human mission.
 - If robotic missions suggest the absence of life, backward contamination issues may recede, but forward contamination may still remain an important issue.
- Identification of R&D needs.
 - The development of a “dockable suit” with a non-contaminating airlock and suit don/doff (i.e., putting on/taking off) area.
 - Non-venting life support systems for both habitat and EVA (leakage may not be preventable).
 - Long-term waste containment and mineralization/processing; Subsurface vs. surface storage must be examined.
 - Waste disposal during transit (jettisoning; mineralization) should be considered.
 - Identify if the current list of ALS technology gaps may be relevant to PP.
- Identification of anticipated problems for various scenarios or mission architectures. (e.g., What if life is discovered before human launch?)
 - Back contamination issues will be a major issue; possibly restricting future missions to robotic missions only.
- Identification of contingency events.
 - Need to identify contingencies and fault tolerance relative to PP; this may become an exhaustive list. For example, what are the implications of an accidental breach with ET material entering spacecraft; fires; cabin air venting to external environment; etc?
- Unresolved issues or concerns for discussion at future workshops or meetings.
 - Identifying biosignatures – “signs of life”; what methods are available to develop comprehensive lists?

- Discrimination between Earth-induced and Mars-induced illnesses that result from biological entities (*e.g.*, common cold vs. martian pathogen).
- Analysis of what materials may be released during leakage.

5.3.4 Gap Identification and Prioritization

The General Breakout Groups were also asked to identify knowledge/technology gaps and prioritize discussion topics and issues listed in the Specific Breakout Group Tasks. The list below indicates the questions/topics that were identified by the groups (underlined), followed by the group findings or comments.

- Identify what information is to be gathered from precursor robotic missions. - This may already be underway by MEPAG (for both planetary science and PP).
- Is a contained jettison feasible when relying on atmospheric incineration in Mars atmosphere? If not, would this incineration be possible for liquid and gas release? - Discussion on this topic was held throughout the deliberations.
- What quarantine requirements and facilities are required to adequately support PP? - Facilities for robotic spacecraft and samples have been discussed, but not for astronauts. The return flight has been suggested as part of the quarantine, but this may not be adequate; medical facilities and tests in the spacecraft for evaluations will not be adequate. A series of NASA-sponsored workshops on this topic should be identified. Consideration of required medical tests would be appropriate to be included during return flight. This may be responsibility of NASA's Chief Medical Officer.
- Discussion on NPR 8020.12C Specifications (NASA's current PP requirements for robotic missions) - Planetary Protection Policy and the Outer Space Treaty are for preserving integrity of science and not for ethical reasons.
- Jettisoning of wastes and un-needed equipment - This is potentially a complex issue. Trajectory analysis must be performed to determine whether wastes will follow a path that won't interfere with other planets, spacecraft, etc.
- Definition of Biosignatures - The definition of biosignatures must be standardized. Likewise, biogenic organics (and inorganics) that must be controlled will need to be defined. Organics, especially non-biogenics, that are acceptable for release must also be defined. PP is mostly concerned with replicating microorganisms, and preserving science on future missions. PP does not have requirements for organics other than listing of measurements and archiving. Further input is needed from the life detection scientific community.
- Requirements for Waste System Technology Developers – Requirements and other information are needed regarding storage and containment, leakage relative to organics of concern, microbial content, amount of water in stored wastes or storage environments (*e.g.*, subsurface), storage duration, and reliability of containment.
- Use of ISRU - If the biohazards are currently indefinable, how will it be possible to certify process products (*e.g.*, potable water)? This issue primarily regards prevention of back contamination. Additional investigation is required to determine the potential effects on specific Mars localities from which resources were extracted (forward contamination issue).

- Maps of Zones of Minimum Biological Risk – Mapping efforts are required to guide the influence of PP and science requirements, and necessary operations need to be developed to achieve compliance.

6 REPORTS OF SPECIALIZED BREAKOUT GROUPS

6.1 REPORT OF THE ADVANCED LIFE SUPPORT SPECIALIZED BREAKOUT GROUP

6.1.1 Participants of Specialized Breakout Group 1 – Advanced Life Support

Leads: John Hogan and John Fisher

Group Members:

Daniel Barta
Joe Chambliss
Alan Drysdale
Aaron Mills
Frederick Smith

6.1.2 Group Charge

The ALS Specialized Breakout Group was required to identify issues that could interface with PP within the individual program elements, namely: Waste Management, Water Recovery, Air Recovery, Food Systems, Thermal Control, Biomass Production and System Integration Modeling and Analysis. The specific charges for the ALS group are listed below:

- State major findings and assumptions about PP considerations, as you understood them, that will impact ALS R&TD rationale.
- Identify critical open issues/uncertainties relative to PP that affect ALS R&TD (unknowns).
- Identify potential contaminants and pathways for ALS systems with respect to forward and backward contamination.
- Identify plausible mitigation alternatives and obstacles for pertinent missions.
- Identify topics that require further research and technology development and discuss development strategies with uncertain PP requirements.
- Identify PP requirements that impose the greatest mission/development costs.
- Identify PP requirements/topics that require further definition.
- Develop overall recommendations on planetary protection relative to ALS development.

6.1.3 Background Information

The Advanced Life Support (ALS) Program represents a suite of enabling capabilities necessary to support human exploration missions. Advanced regenerative life support systems, including air revitalization, water recovery, thermal control, solid waste management, advanced food technology and crop systems, are key capabilities needed to decrease the mass, energy and volume of future spacecraft. Key aspects will include “closing the loop” to recover usable mass, utilizing *in situ* resources, decreasing requirements for expendables, energy, volume, heat rejection and crew time, while

providing a high degree of reliability. Remote missions will require increased contingency response capabilities for prevention and recovery from events, such as fire and hardware failure, that may threaten mission success and crew safety. Spacecraft and surface habitats will need additional capabilities to accommodate new environments, longer periods of service, and unique mission operations.

Development of human life support systems will be constrained by a wide variety of highly integrated technology drivers including:

- Basic human life support requirements
- Specific mission requirements (e.g., mission location and duration)
- Manned systems integration standards
- Volume, mass, heat rejection, power, crew time
- Safety, reliability, maintainability, etc.
- Psycho-social factors and crew preference

Planetary Protection represents an additional set of requirements that life support system developers have generally not considered. Life support systems have substantial potential to contribute to both forward and back contamination of Mars. In particular, supporting humans involves the transport of a large quantity of gases, liquids and solids to and from humans (*i.e.*, a large organic inventory). As materials are consumed, numerous potential wastes are generated. These include (see Hanford, 2004 for more complete example waste models):

- Human fecal and hygiene wastes
- Trash, including food packaging, hygiene wipes and paper
- Make-up gases for gases lost by cabin leakage
- Systems wastes: non-regenerable particulate filters and spent sorbents
- Thermal fluids consumed by evaporators, boilers and sublimators
- Gaseous, liquid and solid by-products from processors
- Inedible plant biomass
- Used clothing
- Used medical supplies

Materials cycling within human rated habitats have the potential to be highly contaminated with microbial life that, if released outside of the habitat, represents a significant forward contamination potential. Conversely, any putative martian life forms that enter the habitat have the potential to become established either in humans, materials or hardware. These organisms may then be transported to Earth on the return voyage, leading to potential back contamination. ALS systems will therefore be strongly influenced by both forward and back contamination regulations.

Likewise, supporting scientific investigations regarding the search for current or past life on Mars will also drive ALS system design, potentially to more restrictive levels. Of particular interest will be control over the release and dissemination of biosignatures from humans, wastes and hardware materials.

PP and scientific constraints therefore will likely influence the selection of life support operations for future human planetary exploration missions. Forward contamination regulations might affect the discharge of solids and liquids, and gases. For example, waste management systems may require processing and containment to rigorous PP standards prior to disposal (Hogan *et al.*, 2005). The venting of unwanted gases from air, water and waste processors may also be subject to control of microbial and/or gaseous components (*e.g.*, certain hydrocarbons). Crew protection and back contamination issues might affect ISRU operations, particularly those that generate resources that can be inhaled or consumed by the crew. Additionally, waste, water and air management systems will need to manage contaminants that enter the habitat through crew EVA operations, and returning samples or hardware. Additional examples of potential influences on life support systems include:

- Closing mass loops to reduce organic inventory and the amount of material that requires discharge and/or venting to the martian surface.
- Altering or restricting certain kinds of operations or processes (*e.g.*, adding microbial filters on vent lines).
- Necessitating that certain operations be performed (*e.g.*, sterilization of disposed wastes).
- Restricting what life/materials can be brought on a mission (*e.g.*, microbial extremophiles).
- Creating needs for new capabilities/technologies (*e.g.*, extended containment).

Ultimately, there will be an effect on mission costs, including the mission trade space. Therefore, PP and science requirements need to be considered early in technology development efforts.

6.1.4 Starting Assumptions

Additional starting assumptions were developed by the group to supplement the preliminary list developed prior to the workshop.

- Foremost, the general consensus was that prevention of unwanted back contamination was the highest priority of PP. It was also agreed upon that a human surface mission to Mars will almost certainly result in the contamination of the internal habitat with martian materials. Even careful planning and specialized EVA suit design will require a number of seals that will likely become exposed to the martian environment. It is anticipated that these materials will circulate within the cabin atmosphere, and eventually contaminate life support systems. ALS systems will therefore need to be designed and operated to control the exposure of the crew to these materials, as well as to rigorously control the transport of these contaminants back to Earth.
- Likewise, the presence of humans will certainly contaminate the internal habitat with terrestrial microorganisms and biosignatures. These materials will likely be transported to the martian environment via intentional/unintentional release during life support operations, and ingress/egress operations for EVA. ALS systems will

need to be designed and operated to reliably control such releases as per PP and science program constraints.

- Both the PP and science programs will levy requirements that will affect ALS system design. PP regulations will be primarily restricted to the transfer of viable life forms to and from Mars. Scientific constraints may control not only the transfer of viable life forms, but also certain materials that may interfere with the investigation of past or current martian life (*i.e.*, biosignatures). The methods employed by ALS systems to comply with PP and science issues may display a large overlap, but also may require specific development for each type of constraint.
- Increasing the level of ALS system closure may enhance compliance with PP and science requirements because it decreases the amount of waste materials (solids, liquids and gases) that might otherwise require venting or discharge from the habitat. Likewise, recycling materials will decrease the overall organic inventory on the mission, which lowers the overall potential to contaminate Mars.
- Due to the potentially prohibitive cost of returning waste materials to Earth, as well as the increased potential for back contamination, it is desirable to have wastes remain on Mars upon mission completion. Several processing and containment methods could be utilized for storage operations on Mars. Currently, there are no assumptions on how storage/disposal will be accomplished.
- ALS processes that have the capacity to sterilize materials as part of their operation may inherently possess more benefit in fulfilling PP regulations than those that do not. For example, a solid waste processor that produces a sterile product facilitates the storage of materials on Mars without the potential for forward (microbial) contamination. Likewise, sterilizing technologies may also aid in the prevention of back contamination, and support crew health and safety.
- The establishment of gas leakage rate requirements on habitats may affect ALS system design and development, and potentially require large scale hardware tests for verification.
- PP regulations will vary in accordance with mission element and type. For example, systems that will be transported to and from Mars will have different design criteria than those that remain on Mars. Similarly, mission progression may create either increases or decreases in the strictness of regulations. For example, after the third Apollo landing mission, PP regulations were lifted, as no evidence of life was found on the moon. Table 1 discusses potential architectural considerations for PP with respect to mission element.

TABLE 1. MISSION ELEMENT ARCHITECTURAL CONSIDERATIONS FOR PLANETARY PROTECTION

Mission Element	Architectural PP Considerations
Crew Exploration Vehicle	A version of the CEV may be used in Mars missions through spacecraft evolution development – Consider PP in original designs
Extended Lunar Surface	A version of the Lander may be used in Mars missions through spacecraft evolution development – Consider PP in original designs
Long Duration Lunar Surface	A version of the Habitat may be used in Mars missions through spacecraft evolution development – Consider PP in original designs; May be used in part as a test bed for PP for Mars; it is desirable that the lunar habitat/lander architecture, relevant systems and airlock/dust lock be similar to a Mars mission.
Mars Vicinity	Transit vehicle will be a vector for forward contamination and backward contamination; potential use for “quarantine” during return trip; consideration needed for return of Mars samples.
Pressurized Rover	Interface for both forward and backward contamination; Cleanliness may be difficult to achieve.
Mars Habitat & Lander/ Ascent	Interface for both forward and backward contamination. Special considerations needed for 1) airlock/dust lock/rover lock; 2) spacecraft docking; 3) transition between hypo and micro gravity; 4) provision for Mars sample transfer and storage.

6.1.5 Critical Open Issues

Task: Identify critical open issues/uncertainties relative to PP that affect your R&TD (unknowns).

Development of appropriate ALS systems for Mars missions in a timely and cost effective manner requires a comprehensive effort in overall requirements generation. This process may be time consuming and iterative. Therefore, preliminary identification of the most critical factors will facilitate ALS technology development to proceed with increased confidence. Listed below are significant unknowns with respect to PP issues that need to be addressed to facilitate ALS R&TD decision-making. In general, many of the issues need to be addressed early in the development cycle.

- **Establishment of general PP requirements** – Currently, detailed PP requirements for human Mars missions do not exist. Development of ALS systems requires a reasonable set of PP guidelines to guide overall efforts. In particular, forward and back contamination requirements will drive systems used in the transit and habitation vessels, and could have a substantial impact on both component and system level design. Individual requirements are needed regarding the release of Earth life to the martian environment, and vice versa.

- **Uncertain values for restrictions on disposal of waste materials** – A primary issue within ALS involves the design for disposal of solids, liquids and gases during and after mission completion. Areas of uncertainty include; the required probability of containment failure, duration of containment, characteristics of disposed material (*e.g.*, sterile), and effect of container location and subsurface depth. Additionally, a potential requirement for waste disposal is the concept of reversibility, which involves the ability to recover disposed wastes in subsequent missions should the need arise. Therefore, issues such as positioning the wastes for retrieval and needed containment duration need resolution. Similar issues exist regarding the venting of habitat liquids and gases to the martian environment.
- **Biosignature definition and release limits** – Currently, there is no formal determination of what compounds will be designated as biosignatures, and the concentrations that could interfere with scientific investigations. Once biosignatures have been defined and identified, a list of their individual limits for release will need to be established. This is subject to a complex set of factors including biosignature longevity in the martian environment as well as the potential for dissemination due to wind and EVA operations.
- **Quarantining of crew and returning vessels** – The assumption that the crew and hardware will be contaminated with martian materials will likely mandate a thorough quarantine procedure upon return to Earth. Both quarantine and decontamination procedures may influence the design and operation of ALS systems, and possibly mission architecture. It is critical to address this early in the design process.
- **Definition of the approach to control back contamination** – The transfer of the crew from martian habitats to ascent and then transit vehicles will likely be influenced by back contamination regulations. For example, the crew may undergo decontamination procedures at each transfer point, and minimize the total transfer of materials at each step. This also involves the storage, transfer, and transport of martian samples. It is plausible that these protocols/design features could also influence ALS system development.
- **Definition and identification of zones of minimal/maximal biological risk** – The extent to which ALS systems will be constrained by both forward and back contamination regulations may be strongly driven by site of martian habitation and surface operations. Minimizing the potential for cross-contamination may allow more relaxed ALS system requirements, and vice-versa.

6.1.6 ALS R&TD Needs Resulting from Planetary Protection Requirements

Task: Describe the changes to your R&TD program that you believe will be necessary when PP requirements are defined/flowed. Be specific about the technology areas that may need to be stopped/redirected/accelerated/started in development. Discuss development strategies that can address the lack of certain PP requirements.

The ALS Program has numerous and highly integrated sub-elements, which leads to a complex array of potential responses to future (*i.e.*, unknown) PP requirements.

Regardless, generalized predictions for R&TD needs are possible and are discussed below:

- **Control of forward contamination (including biosignatures)** – ALS systems can control forward contamination through various means. Microbial destruction and/or control can be implemented via mineralization, sanitization, sterilization, stabilization and containment of final waste products. This includes both Earth-based and ET life forms. Stabilization/mineralization of waste materials will also decrease the biological and chemical reactions during storage/disposal or further processing steps. This also can reduce or eliminate potential microbial substrate that could be used for the proliferation of ET life. General housekeeping operations can also employ frequent decontamination operations, such as microbial disinfection of surfaces. Many science-based requirements could likewise use the above-listed methods, and may require even more stringent operations to control biosignature release.
- **Containment of disposed waste materials** – It is almost assured that PP and science requirements would initially necessitate the containment of solid and liquid materials discharged to the martian environment. The level of influence on ALS system design will depend on the level of containment required (release standards), the state of the material being contained (*e.g.*, dried, sterilized, mineralized), the duration of containment (*e.g.*, >50 years, or a period that ensures reversibility), and positioning of the containers (above or sub-surface). Containers may be required to be relatively durable if stored external to the habitat, and may impose a substantial mass and volume penalty. Overall containment requirements will also be driven by the waste processing systems that are employed. For example, compaction and mineralization can significantly decrease the needed storage volume. Likewise, mineralization, sterilization and drying can also reduce the potential for forward contamination, and may decrease the volume and mass of containment systems.
- **Control of venting** – The venting of gases may be regulated by PP and science constraints to various degrees. Examples of requirements include the control/elimination of particulates of living and dead life forms, as well as the control of certain gases (deemed to be a biosignature) that interfere with scientific measurements. All ALS systems, and the habitat in general, will therefore need to either selectively control or eliminate vented gases. Particle filters and air treatment systems such as adsorbents and catalytic systems may be employed. Elimination of gases would require either closure of the system with respect to materials cycling, or the capture and storage of unwanted gases, perhaps in spent tanks. Because the martian atmosphere is primarily composed of CO₂, it is likely that spent CO₂ from CO₂ removal systems will be allowed to be vented. However, current CO₂ removal technologies typically expel numerous gases and compounds other than CO₂ in a mixed stream, and may therefore be regulated. Similarly, water and waste processing systems often produce highly contaminated exhaust streams that might require exhaust treatment and/or containment.
- **Control of back contamination** – Numerous ALS systems will be involved in the control of introduced martian materials. The air treatment system will be responsible for removing contaminants from the cabin atmosphere, the water recovery system will be responsible for treating water to ensure control over contamination of crew via

ingestion, and waste processing will need to manage materials that may have been directly or indirectly contaminated with martian materials. Likewise food and biomass production systems may need to develop procedures to control the contamination of human foodstuffs and plant growth chambers.

- **Organic inventory control** – The primary method used in robotic missions to control contamination (PP and science-based) is the reduction of organic inventory. Employing this approach to human missions may result in the preference to mineralize organic waste materials when plausible. Likewise, increased mass closure via recycling will effectively reduce the overall stores. In a related theme, it was discussed that in addition to the dominating load of microbial biomass associated with the human intestinal tract, biological systems that either generate significant amounts of organic material (food production systems) or those that possess high microbial biomass (*e.g.*, biological water and waste processors) may introduce a greater potential for both forward contamination with Earth life forms. It was also noted that the presence of biological systems (*e.g.*, humans and other biological systems) may serve as a resource for back contamination by serving as a food source and “incubator”. This was countered by the possibility that martian life may be more suited to inorganic environments, and may survive better in common hardware than in competitive carbon substrate-based biological communities.
- **Re-examine and modify ALS reference mission designs** – Systems analysts can generate initial designs of potential technology suites (and costs) that satisfy (anticipated) PP and science requirements by redesigning current ALS reference mission scenarios.
- **Increase efforts to quantify and characterize ALS system process streams** – Identifying waste, water and air streams is needed to assess forward contamination potential and mitigation technologies.
- **Perform investigations to assess the effect of contaminant releases from the cabin atmosphere via leakage and potential intentional venting operations** - These efforts may require physical simulation and /or test-beds. An important consideration is determining the contribution of the martian environment (*e.g.*, radiation, temperature) towards passive mitigation of forward contaminants.

Strategies for ALS System Development Given Uncertain PP Requirements:

PP regulations, waste streams, and ALS system requirements require further definition for human Mars missions. Additionally, established requirements may be altered as information from future robotic missions becomes available. Regardless, technology development must progress to meet the anticipated mission timelines. Potential methods to minimize development cost and the risk of mission delay and/or failure in the face of uncertain PP and science requirements include:

- Promote acceleration of the definition of PP and science requirements. Incorporate known PP requirements in ALS technology requirements and be responsive to changes in knowledge regarding the martian environment. Provide ALS data to support PP requirement development.

- Maintain communication between and among PP and other communities (*e.g.*, MEPAG) to enhance co-evolution of requirements generation.
- Identify critical technology gaps in ALS technology availability that are required to satisfy predicted PP and scientific regulations.
- Develop ALS systems that are flexible in application over various mission segments/scenarios. For example, modular waste containment systems could be designed that would function effectively for transit vehicles and surface habitats, and both inside and outside of the habitat.
- Develop ALS systems that can satisfy conservative PP requirements. These systems will therefore be suitable to a broader range of mission needs, and will be more suitable should life be found on Mars either before or during the mission.
- Perform system analyses that identify the full range of potential mission-specific conditions and then select/design ALS technology suites that satisfy the bulk of the most plausible conditions. Examine the degree of closure as a method to support PP/scientific requirements.
- Perform sensitivity analyses of specific PP/science-based requirements. This involves the identification of scientific and technical requirements that are the most influential, and addressing these first if possible.
- Develop a priority of preferred means of complying with PP requirements. For example, it is probable that overall risk reduction will likely stem from the elimination of potential contaminants, rather than mere containment. Less secure methods may meet PP regulations solely by containment with no reduction in life or organic inventory. These preferences will serve as additional input to the overall ALS system selection process.

6.1.7 Contaminants and Pathways

Task: Identify potential contaminants and pathways for ALS systems with respect to forward and back contamination.

Potential Forward Contaminants:

Numerous types of materials used in space missions become wastes, and require management of some form. In addition to the commonly considered materials (see list below), it is necessary to consider the status of the various vehicles, rovers and habitats after final use. Due to the high cost of up-loading from planetary surfaces, large units will likely be left on the planet surface, potentially with large amounts of waste solids, water and gas. If they are not reused in the future, the vehicle and its contents are technically wastes, and require a termination management plan.

- **Human life support system wastes** – Human life support systems span multiple system types, and can produce vast amounts of waste comprising numerous constituents. IExamples include, but are not limited to, human solid wastes and wipes, medical wastes, clothing, paper, trash, tape, food waste, inedible biomass from crops, packaging, wastewater brines, EVA wastes, biological processor system wastes (*e.g.*,

sludge), filters and free or tanked gases. Many of these wastes will be sources of life forms/biosignature materials (even certain inorganic materials). Additionally, ALS systems utilize orbital or field replacement units that require intermittent replacement. This could generate wastes ranging from small pieces such as o-rings, to full-scale hardware systems, such as redundant water treatment units.

- **Payload wastes** – These include materials generated from a broad array of scientific investigations, and may consist of numerous types of chemicals, solids, and biological materials.
- **Planetary investigation wastes** – In addition to payload science wastes, other wastes may be generated during the study of martian surface materials. For example, surface samples will require a high level of containment and sanitation during investigations, potentially generating consumable materials needed to prepare and preserve samples and disinfect and clean surfaces and equipment. These materials are prominent sources of back contamination.
- **Thermal/Power generation system wastes** – Various waste types may be generated from thermal control/power systems, including radiators, heat exchange fluids, solar arrays and nuclear wastes. Some systems will emit large amounts of waste heat, and can potentially disrupt local environments/ecology (*e.g.*, melting of surface ice).
- **Miscellaneous** – Materials normally not anticipated to enter the WM system may have been inadvertently overlooked, or may be generated during off-nominal events. Mission-specific waste analyses will be necessary to identify these potential sources, and develop contingency management plans.

Potential Forward Contamination Pathways:

The major identified forward contamination pathways are listed below:

- **Egress of humans, equipment and samples** – EVA activities possess a strong potential to act as a vector for introducing Earth life/biosignatures to the external environment, as it is practically impossible to sterilize and clean suits and equipment materials in a complete and consistent fashion. EVA suit engineering efforts may be able to minimize such transfer by designing suits that remain external to the habitat/rover, while allowing a hatch that seals against the vessel for human transfer. Regardless, some contamination is expected, particularly when samples and equipment are transferred in and out of the vessel. Decontamination procedures may be required.
- **Storage and/or disposal of wastes on planetary surface** – Surface storage of wastes would isolate them from the crew, recover internal habitat volume, reduce the opportunity for back contamination, and greatly minimize return propulsion costs. Although surface disposal will likely utilize containment, it is inevitable that all containers will eventually fail. Only the extent of leakage and container life-span are

variable and contained contents will be released at some point. Therefore, it must be determined if storage/disposal on the surface is acceptable, and if so, what level of containment (*i.e.*, release standards) is required, the required state of the stored/disposed wastes, and how long containment must endure. Burial of containers under the surface would serve to indefinitely contain most wastes if the container failed. However, underground storage may shield the wastes from the destructive forces of radiation, and may enhance the possibility of unwanted infiltration into martian ecosystems (via potential liquid aquifers).

- **Leakage from habitat, airlocks and other vessels** – All pressurized vessels leak gases to some extent, based on the pressure differential and the degree of “gas-tightness”. While vessels can be designed to minimize leakage rates, this typically imposes a mass penalty. Intentional venting of waste gases to the planet atmosphere is performed to ensure crew safety and to save processing and storage costs. Gases and associated particulates may also be lost during human and equipment egress/ingress operations via airlocks. Off-nominal losses may also occur during unplanned vessel depressurization, or safety pressure-relief valves. Water losses in liquid or gaseous form may occur through similar mechanisms, or through line ruptures. There is no anticipated mechanism where solid wastes (other than airborne particulates) would nominally “leak” from a vessel. Instead, a significant rupture, depressurization or other opening would likely be required to allow solids to flow overboard. Such an event would have the potential to release large amounts of contaminants, and must be considered when establishing operational protocols.

Potential Back Contaminants and Pathways:

For purposes of this discussion, back contamination is technically defined as martian life² and any martian solid or liquid material that is considered a potential vector of martian life. Such contaminants can enter via nearly any contact/exchange with the martian environment, and have the potential to negatively effect human health and safety, and possibly Earth ecosystems. It is anticipated that EVA, ISRU operations, and spacecraft docking/personnel transfer will be significant back contamination pathways. Primary mechanisms include EVA ingress/egress with associated equipment and geological and astrobiological samples, airlocks/transferlocks/dustlocks, spacecraft docking mechanisms, and ISRU resource generation and use. Back contaminants that enter habitats are anticipated to become widespread throughout nearly all ALS systems via airborne transmission, contact transfer (*e.g.*, sample handling, multiple surface contact) and internal systems transport (*e.g.*, water lines, filters). Back contamination can also be returned on the external surfaces of spacecraft that have been in contact with the martian environment.

² Even if it is uncertain whether martian life exists, PP controls will likely reflect a conservative approach similar to that recommended by the NRC (1997) for Mars sample return missions—namely, all materials will be considered biohazardous until proven otherwise by rigorous analyses.

6.1.8 Mitigation Alternatives

Task: Identify plausible mitigation alternatives and obstacles for specific mission types and segments (*e.g.*, transit, surface stay).

Forward Contamination Mitigation Alternatives:

- Inter-planetary disposal of wastes, liquids and gases generated during transit mission to Mars will decrease the amount of contaminants and organic inventory that are near or on Mars and Earth.
- Preferentially employ processes that destroy terrestrial and ET life, and their potential for later reestablishment. Representative processes include mineralization, stabilization and sterilization, in combination with complementary post-processing containment systems.
- Employ processes that control and decrease organic inventory (biosignatures). This includes mineralization, containment and materials recycling.
- Employ material selection and exclusion practices to reduce or eliminate materials that pose a high contamination risk or complex management operations. Utilize materials that facilitate decontamination (*e.g.*, can withstand autoclaving, chemical disinfectants).
- Develop general procedures (*e.g.*, Hazard Analysis Critical Control Point - HAACP, airlocks) and decontamination (*e.g.*, disinfection wipes) operations for habitat internal surfaces and hardware for both “general housekeeping” and contingency situations. Likewise, decontamination procedures will be needed for equipment, EVA suits, waste containers, etc. that undergo egress.
- Utilize vent-less life support processes and processing vented materials.
- Employ system-level designs that minimize contamination risk, including habitat zoning or compartmentalizing and/or independent controls and life support such as isolated, independent ventilation systems.
- Utilize contaminant monitoring and alarming systems to provide real-time verification of ALS system performance (See AEMC section).
- Design interfaces with EVA, airlocks and rovers to control contaminant transfer.

Back Contamination Mitigation Alternatives:

- Minimize the amount of materials that have contacted the martian environment which are brought back into the habitat or returned to Earth. This could entail leaving materials on Mars, or jettisoning them in interplanetary space prior to Earth entry.
- As with forward contamination, preferentially employ ALS processes that destroy potential martian life, and their potential for proliferation/reestablishment.
- Develop general nominal and contingency procedures and decontamination operations for internal habitat surfaces/systems, and for equipment, samples, EVA suits, etc. that undergo habitat ingress, and/or that will be returned to Earth.

- Consider storing samples to be returned to Earth outside the habitation compartment of returning vessel to support crew health and safety. Potentially enclose samples in external compartments that are designed to ensure sample integrity and jettisoning if required.
- Develop protocols for the transfer of personnel, materials, and hardware from contaminated vehicles to clean vehicles during Mars ascent, Earth transit and landing.
- Consider developing systems to minimize gravity-settled materials (including contamination) from becoming airborne after lift-off (as vehicle transitions from Mars fractional gravity to microgravity).
- Develop monitoring systems that can signify the potential presence of back contaminants, with associated alarming systems (see AEMC report summary).
- Employ system-level vehicle designs that minimize contamination risk, including habitat zoning or compartmentalizing and/or independent controls and life support.

6.1.9 Identification of Major Obstacles

Task: Identify PP requirements that impose the greatest mission/development costs for ALS

- “Breaking the chain of contact” for backward contamination. Although the workshop consensus was that breaking the chain of contact from Mars to Earth is nearly impossible, minimization will be sought. This will entail avoiding contamination of the humans and hardware via multiple technological and operational steps. This may involve operations on Mars surface or orbit, transit, Earth orbit, and Earth surface activities, and could influence overall mission architecture.
- Rigorous constraints on material releases to the martian environment, especially the management of solid and liquid wastes. This could entail the development of sophisticated processors and disposal systems. The venting of gases can readily be managed to comply with PP requirements (*e.g.*, microbial filters), but potential scientific constraints may require substantial processing. Additional impacts will be imposed upon thermal, food technologies and biomass production systems.

6.1.10 Planetary Protection Requirements Definition

Task: Identify PP requirements/topics that require further definition.

- Identification of materials that are considered to be contamination (PP and scientific), and the levels of release that will be allowable.
- Definition and identification of zones of minimal and maximal biological risk, and their effect on ALS system development for specific missions.
- Examine the potential for interplanetary disposal during transit, and what conditions would be imposed concerning expulsion, trajectory, proximity to planetary bodies, waste state and types.

- Determine if storage or disposal of wastes will be allowed on/below the martian surface, or in abandoned vehicles. If so, identify containment requirements regarding duration, efficiency, waste state, degree of certainty, etc..
- Determine constraints as to what will be allowed to be returned to Earth (*i.e.*, potential for back-contamination). Identify quarantine procedures that will be required for samples, crew and returning vessels.
- The inside of the returning spacecraft may be contaminated to some degree. Therefore, identify how ALS systems can support back contamination control in all phases of the mission.
- Identify how ALS operations must be conducted to control forward contamination (*e.g.*, increased bioloads on suits and equipment, venting gases/liquids/particulates to planetary atmosphere via airlocks). For example, how "clean" does the habitat need to be in order to support external PP requirements?
- Identify special measures that should be taken to avoid the propagation of putative extraterrestrial organisms in ALS (and other) systems.
- Examine how ALS technologies will manage contingency situations, such as unexpected waste generation from planned or unplanned biological experiments, or the discovery of free-living extraterrestrial life in the habitat.
- Identify the types of ALS monitoring and control systems, procedures and equipment that are necessary to assist in implementation and verification of PP compliance. This includes issues regarding contamination of the planetary surface, habitat contamination and return of spacecraft, astronauts and samples to Earth.

6.1.11 Overall Recommendations

Task: List major conclusions from group deliberations.

- PP and science-based requirements will have a strong effect on ALS system R&TD. Scientific limitations on releases of hydrocarbons or other chemical/materials may exert a stronger impact on some R&TD costs and efforts than PP requirements. Overall, these requirements affect technology trade options and development costs. Development of PP and scientific requirements for human missions should be accelerated, especially in the areas of discharge and disposal limits, backward contamination limits, and ISRU.
- The ALS community should identify the potential for forward contamination via further definition of initial material inventory, process products and release mechanisms. This information must be shared with the PP and scientific communities to facilitate requirements generation.
- Identify critical ALS technology and requirements gaps. Use best estimates of available PP, scientific and ALS requirements to guide ALS technology development accordingly. Employing conservative (stricter) requirements should be considered as it yields technologies that possess increased functionality and mission applicability.

- Perform analyses of mission scenarios using various ALS technology suites to comply with predicted requirements early in the development process. If the calculated costs of plausible solutions are deemed excessive, seek further verification or reexamination of PP and scientific requirements, and/or identify alternative ALS system R&TD needs.
- It is imperative to maintain open communication between the PP, scientific, AEVA, AEMC, ALS and other relevant communities regarding advances in knowledge related to PP requirements and concerns. These systems operate in an integrated fashion, and require coordination for mission success.

6.2 REPORT OF THE ADVANCED EXTRAVEHICULAR ACTIVITY SPECIALIZED BREAKOUT GROUP (2)

6.2.1 Participants of Specialized Breakout Group 2 – Advanced Extravehicular Activity

Lead: Joseph Kosmo

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6.2.2 Group Charge

The AEVA Specialized Breakout Group was responsible for examining the influences of PP issues on the task of providing humans with portable life support systems and vehicular mobility. Specific charges are listed below: The AEVA group was charged with the following tasks:

- Identify potential contaminants and pathways for AEVA systems with respect to forward and backward contamination.
- Identify plausible mitigation alternatives and obstacles for pertinent missions.
- Identify topics that require further research and technology development and discuss development strategies with uncertain PP requirements.
- Identify PP requirements that impose the greatest mission/development costs.
- Identify PP requirements/topics that require further definition.
- Develop overall recommendations on PP relative to AEVA development.

6.2.3 Background Information and Starting Assumptions

Background Information: The present Shuttle space suit system, or Extravehicular Mobility Unit (EMU) has been in use since 1981, and has accumulated a significant

number of operational hours in that time. In addition, airlock systems on both ISS and Shuttle have been in operation long enough to understand the operational implications associated with operation of airlocks on the martian surface. Martian planetary surface airlock operations, based on ISS configuration (2-crewmember size) would be expected to conduct a depressurization cycle that would store the gas in the airlock until reaching a pressure of ≈ 3.0 psia. Once at that level, the residual gas, including any included spores, biosignatures and other material, would be vented to the external environment. This includes ≈ 2.0 pounds of gas per depressurization cycle. Due to the high power requirements to pump out this final fraction, it is unlikely that airlock designs for Mars would be able to avoid that final venting to the environment.

Preliminary design concepts based on a new “minimum volume” design can reduce that vented volume to some extent. Assuming the volume of the airlock can accommodate two crewmembers, and the residual volume is ≈ 2 times the suited crewmember volume, the gas vented to the environment at the end of depressurization is expected to be 0.97 pounds per cycle. However, a minimum volume airlock will aggravate back contamination concerns due to issues associated with donning and doffing EVA suits, unless a “suit-port” type of airlock is adopted. Evaluations of suit port designs are presently underway; however, it is still expected that a volume of air ≈ 1 pound per airlock cycle will be vented to the martian environment with every air lock cycle.

Space suit leak rates can be approximated using the Shuttle EMU, which has measured leak rates. The total suit assembly leakage based on a representative Shuttle EMU is indicated in Table 2 (each suit):

TABLE 2. TOTAL SUIT ASSEMBLY LEAKAGE RATES/SUIT

Component	Ground Leakage	In-Space Leakage
Arms (each)	31.5 sccm*/air	9.0 sccm/O ₂
Lower torso	24.5 sccm/air	7.0 sccm/O ₂
Gloves (each)	10.5 sccm/air	3.0 sccm/O ₂
Upper torso	21.0 sccm/air	6.0 sccm/O ₂
Helmet	7.0 sccm/air	2.0 sccm/O ₂
TOTAL LEAKAGE	136.5 sccm/air	39.0 sccm/O ₂

*sccm = standard cubic centimeter per minute

Additional leakage of constituents from portable life support system (PLSS) comes from the following areas:

- Vent system loop (connector fittings)
- Oxygen supply source (gaseous or cryogenic)
- Heat removal system (water boiler; ~ 1 lb/hr.)
 - (Note: If a water boiler is used, constituent water will contain and may release contaminants from the ALS water processor system)

Venting systems for regenerable CO₂ and humidity control are currently among leading contenders to limit expendables and reduce on-back weight. These systems, however, will release ullage (unfilled) volume of space suit atmosphere as well as separated CO₂,

H₂O, and internal trace contaminants, including ≈ 2 lbs CO₂/EVA, ≈ 1.5 lbs H₂O/EVA, ≈ 0.02 lbs O₂/EVA, as well as other contaminants. Higher O₂ losses are possible with ejectors and other possible technologies. Finally there are other potential venting considerations during assisted operations, emergency operations, external EVA recharge or equipment change-out activities.

There are additional potential contamination constituents associated with EVA operations, which include:

- Trace chemical contaminants associated with suit leakage
- Lubricants associated with surface support vehicles and suit bearings
- Suit surface contaminants from habitat and human contact
- Elastomeric/fabric materials from surface support vehicles and outer materials of space suit
- Mechanical abrasion of external suit components against vehicle surfaces and martian outcrops
- Off-gassing of volatiles associated with organic compounds used in the suit outer layers

Starting Assumptions: Basic robotic mission PP guidelines and requirements, if applied to equipment and hardware on human-based missions are deemed unrealistic and most likely un-achievable in terms of sterilization and levels of microbial spore densities. Due to the nature of EVA systems, particularly pressure garment assemblies and portable life support systems, leak rates will always be >0 , and pathways exist for release of spores and biosignatures to the martian environment.

- For forward contamination concerns, the basic assumption is that missions carrying humans to Mars will contaminate the planet.
- For backward contamination concerns, the basic assumption is that humans inevitably will be exposed to Mars surface materials.

6.2.4 Contaminants and Pathways

Identified Forward Contamination Issues:

- **Leak Paths and Rates Associated With Candidate Advanced Planetary EVA Systems:** The present planned EVA suit for advance planetary operations is based on the concept of a modularly-constructed suit assembly to increase logistics, interchangeability and commonality of components. This concept is represented by planetary prototype NASA-JSC MK III advanced technology suit. As part of this effort, the team identified ≈ 50 separate potential leakage path areas represented by static seals, dynamic seals, and connector hardware pass-thru locations. This does not take into consideration all individual gas bladder heat-sealed or adhesively-bonded seams or natural permeation characteristics of the bladder material based on wear and abrasion. The potential leak paths include:
 - Helmet to neck-ring
 - Neck-ring to hard upper torso

- Rear hatch to hard upper torso
- Shoulder joints to hard upper torso (2 ea.)
- Shoulder bearings (2 ea.)
- Upper arm bearings (2 ea.)
- Upper arm sizing elements to elbow joints (2 ea.)
- Lower arm sizing elements to elbow joints (2 ea.)
- Wrist disconnects to lower arm sizing elements (2 ea.)
- Glove disconnects w/bearings to wrist disconnects (2 ea.)
- Glove assemblies flange-mounted to glove disconnects (2 ea.)
- Waist ring to hard upper torso
- Waist bearing
- Waist ring rolling convolute joint to brief element
- Upper hip bearings to brief element (2 ea.)
- Upper hip bearings (2 ea.)
- Mid-hip bearings (2 ea.)
- Lower hip bearings (2 ea.)
- Lower hip bearings to abduction/adduction ring (2 ea.)
- Abduction/adduction ring to upper leg sizing (2 ea.)
- Upper leg sizing elements to knee joints (2 ea.)
- Lower leg sizing elements to knee joints (2 ea.)
- Lower leg sizing elements to ankle bearings (2 ea.)
- Ankle bearings (2 ea.)
- Ankle bearings to boot flange interface (2 ea.)
- Boot flange interface to boots (2 ea.)

Despite the number of leak paths, the robustness of the MK III suit is indicated by the fact that after ≈ 950 hours of pressurized use over the past 17 years, total leakage rates are on the order of 1,500 – 2,000 sccm after normal 40 hour maintenance periods. In addition, the MK III suit has been run for most of its life in a terrestrial pressure environment. Leak rates in the ≈ 0.01 atm martian environment are expected to be considerably lower.

- Humans produce a variety of trace contaminants that are present in the atmosphere of the pressure garment. Some portion of these contaminants will inevitably be vented to the martian environment. The list of relevant contaminants produced and their allowable concentrations in the spacecraft atmosphere are presented in Table 3.

The above values represent trace contaminant human products that would be components of all space suit leakage and vent gases from airlocks/habitats. Various toxicological trace contaminant products and Spacecraft Maximum Allowable Concentrations (SMAC's) for Selected Airborne Contaminants developed by the National Research Council Committee on Toxicology can be found on web-site: <http://www1.jsc.nasa.gov/toxicology/SMACbooks.htm>. In addition, materials used in construction of the pressure garment are allowed to off-gas a wide range of organic and inorganic molecules, a short summary of which is provided in Table 4.

TABLE 3. TRACE CONTAMINANT PRODUCTION RATES AND ALLOWABLE ATMOSPHERIC STANDARDS

Compound	Production Rate From Humans, g/day	Maximum Allowable Concentration, ppm
Ammonia	0.25	25
Methane	0.047	1000
Acetaldehyde	0.000083	10
Acetone	0.00013	100
Ethyl Alcohol	0.004	17
Methyl Alcohol	0.0014	13
n-Butyl Alcohol	0.0013	3
Methyl Mercaptan	0.00083	0.1
Hydrogen Sulfide	0.000075	1

Any compounds associated with presumed martian organic life that are being planned as biosignatures may potentially be confused with any of the above compounds produced and vented by the human and/or the EVA system.

Identified Backward Contamination Issues:

- Backward contamination pathways exist during normal EVA surface operations. These pathways represent the kinds of operations that will take place on a daily to weekly basis, and they include:
 - Airlock operations
 - Transport of dust and regolith materials from surface into airlock and subsequent habitat living areas
 - Crew contamination during don – *e.g.*, inhalation/ingestion during EVA or inseparable contact transfer into habitat and to Earth.
 - Return from remote EVA worksites and surface traverses
 - Transport of “non-documented/classified” surface materials back into airlock/habitat living areas
 - Geologic/Astro-biological sample collection activities (surface and sub-surface operations)
 - All of the above concerns associated with human-assisted operations
 - Handling of samples *in situ* or in habitat laboratory for analysis
 - Transfer EVA prep / servicing / maintenance items into habitat
 - Surface contaminants and contaminants in cavities, seal regions, porous materials, between layers, etc.
 - Limitations of practicable cleaning processes prior to airlock entry/in airlock
 - ISRU Operations Phase
 - All of the above concerns; perhaps magnified based on the extent of operations

TABLE 4. FAMILIES OF COMPOUNDS THAT OFF-GAS FROM PRESSURE GARMENTS AND ASSOCIATED ALLOWABLE ATMOSPHERIC CONCENTRATIONS

Families of Compounds	Molecular Weight	Maximum Allowable Concentration, mg/m ³
Alcohols (as Methanol)	32	10
Aldehydes (as Acrolein)	56	0.1
Aromatic Hydrocarbons (as Benzene)	78	3.0
Esters (as Methyl Butyrate)	102	30
Ethers (as Furan)	68	0.11
Halocarbons:		
Chlorocarbons (as Chloroacetone)	93	0.5
Chlorofluorocarbons (as Chlorofluoromethane)	68	24
Fluorocarbons (as Trifluoromethane)	70	12
Hydrocarbons (as N-Pentane)	72	3.0
Inorganic Acids (as Hydrogen Fluoride)	20	0.08
Ketones (as Diisobutyl Ketone)	142	29
Mercaptans (as Methyl Mercaptan)	48	0.2
Oxides of Nitrogen (as Nitrogen Dioxide)	46	0.9
Organic Acids (as Acetic Acid)	60	5
Organic Nitrogens (as Monomethyl Hydrazine)	46	0.3
Organic Sulfides (as Diethyl Sulfide)	90	0.37

6.2.5 Recommendations

General. The AEVA community needs realistic guidelines and requirements for EVA PP that are; a) tolerant of EVA hardware systems design feasibility limitations, b) have technical practicality, c) have minimum impact to mission planning and operations, d) have an architecture so as not to affect human functional performance capabilities, and e) are acceptable to both the PP and science communities. These guidelines and requirements will drive cost; the only way to reasonably mitigate these costs is to identify these guidelines and requirements early in the development cycle. With respect to biosignatures, the AEVA community knows gaseous components that vent from the suit,

but it does not know what levels of these constituents are acceptable from a forward contamination or science standpoint.

The AEVA community presently does not know what level of biological material is released from any EMU during the course of normal operations. Therefore, the community recommends conducting human space suit chamber tests to determine biological and chemical signature characterizations generated by current space suit system venting and leakage effluents using sample tracer elements or markers.

The Planetary Protection community needs to develop a classification system of Mars surface sites based on level of scientific interest and define “zones of operation” ranging from “no human contact” to “unlimited contact”. Lastly, the PP community needs to empirically identify and determine what level of microbial spore density and chemical/organic constituents are allowable for EVA surface operations.

Specific Overall AEVA System Recommendations

- Define specific surface task activities that would require the implementation of appropriate PP measures.
 - Need specific input to define tasks and requirements
- Describe and define the potential physical (chemical or biological) impacts that the identified suit/PLSS vent/leakage constituents would have in regard towards PP “forward” contamination concerns.
 - Conduct human suited subject chamber tests to determine the actual products that are vented during suit operations.
- Determine what levels of PP “backward” contamination control are possible or needed for EVA systems(suits, PLSS, airlocks, rovers).
 - Develop appropriate operational protocols to minimize transfer of contamination products into the habitat.
 - Consider the requirements associated with periodic inspection and maintenance, in order to maximize the time between inspection and minimize crew exposure to martian materials.
- Determine what effect the natural martian environment (UV, radiation, thermal, pressure) would have towards “natural mitigation” of potential Earth-based contaminants.
 - Collect/develop information on release/escape of microbes from suits and airlocks and development of detection and monitoring sensors and procedures.
 - Develop suit simulation tests based on human subject testing described above.

6.2.6 Mitigation Alternatives

Task: Discuss Plausible Mitigating Approaches for Human EVA Operations

- Minimize surface contact area of initial human-EVA supported activities:

- Use robotic precursors (tele-operated or autonomous mode) to scout and survey intended EVA worksite locations and potential science way-point stations prior to human intervention.
 - **Obstacle** – Potentially high cost and time overhead associated with robotic vehicle operations; also, limitations associated with robotic vehicles as such (lack of real-time decision making, intuition and judgment)
- Identify “safe” and “no-go” zones adjacent to and within x-radius distance of lander/habitat location and develop method of control for human-EVA supported traffic in the landing area.
 - **Obstacle** – May not be able to totally exclude “chance encounter” with “oasis-of-life”; potentially restrictive for critical surface operations (location of ISRU plant or power-plant distribution elements)
- Reduce or eliminate EVA-system element contamination sources.
 - Vent gases, leakages, trace chemical contaminants, material abrasion, etc.
 - **Obstacle** – Not totally practical; through normal use and wear conditions over time, all potential contamination sources will increase and accumulate. Also a real restriction on life support technology choices
- Screen, identify and catalog all Earth-based “signature” materials associated with EVA-system elements in order to recognize and compare against potential “alien” life-bearing materials:
 - Develop “Contamination Materials Reference Guideline”
 - **Obstacle** – time and cost maybe excessively prohibitive; also, may not fully capture all associated materials and constituents
- To potentially mitigate “backward” PP contamination, quarantine, isolate or discard all EVA surface-exposed hardware items (other than scientific samples) at habitat base-site as a “non-return” to Earth policy:
 - Provide “peel-off layer” over portions of suit to remove/discard prior to airlock entry
 - “Decontaminate” EVA hardware items prior to airlock entry
 - **Obstacle** – need to assess logistics and costs associated with “throw-away” versus “re-use” philosophy.
 - » Limited effectiveness given transfer of contaminants to crew and habitat

6.2.7 R&TD Needs

Task: Identify PP EVA System Topics Requiring Further Research & Technology Development.

- Improved space suit design features consistent with PP needs, especially for the demands of human activities on the martian surface located away from pressurized habitats and rovers (from Race *et al.*, 2003):
 - Define specific surface task activities that would require the implementation of appropriate PP measures
 - Potential modification or redesign of suit/PLSS venting systems applicable to Mars surface situations
- Describe and define the potential physical (chemical or biological) impacts that the

identified suit/PLSS vent/leakage constituents would have in regard towards PP “forward” contamination concerns:

- Determination of levels of filtration that are possible or needed for EVA systems; suits, PLSS, airlocks, rovers
- Information on release/escape of microbes from suits and airlocks and development of detection and monitoring sensors and procedures
- Determine what effect the natural martian environment (UV, radiation, thermal, pressure) would have towards “natural mitigation” of potential Earth-based contaminants.

6.3 REPORT OF THE ADVANCED ENVIRONMENTAL MONITORING AND CONTROL (AEMC) SPECIALIZED BREAKOUT GROUP (3)

6.3.1 Participants of Specialized Breakout Group 3 – Advanced Environmental Monitoring and Control

Lead: Darrell Jan

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6.3.2 Group Charge

The primary task of the AEMC Specialized Breakout Group was to identify and address the monitoring and control needs of human missions to Mars in relation to potential PP regulations. The AEMC group was charged with the following tasks:

- Identify monitoring and control needs to support PP for pertinent missions.
- Identify potential contaminants or effects related to monitoring and control hardware systems (if any).
- Identify topics that require further research and technology development and discuss development strategies with uncertain PP requirements.
- Identify PP requirements that impose the greatest mission/development costs.
- Identify PP requirements/topics that require further definition.
- Overall recommendations.

6.3.3 Monitoring and Control Needs

Task: Identify monitoring and control needs to support PP for pertinent missions.

The group’s understanding is that although the current PP standards for forward contamination control include culturable bacterial spores, other targets (*e.g.*, viruses, prions, eukaryotic cells) could be included in new standards. AEMC, motivated by crew

health requirements, would also target these organisms, though possibly with different emphases and sensitivity levels.

The AEMC group tried to anticipate, as a strawman, a possible level for forward contamination monitoring capability for a human mission. As a first estimate, the group considered the current specification for a *Category IVa* non-life detection mission. (Later the PP group suggested Class 100,000 cleanroom assembly.) The requirement for back contamination was more difficult to grasp, and the group was not able to come up with a strawman specification.

The group expects that monitoring for PP requirements would be required during all phases of a mission: pre-launch, transit, pre-use, surface operations, return, and post-return. The different phases would likely require different technologies and different logistics. It was expected that monitoring would be required both within and outside any crewed enclosure (namely, inside and outside a habitat, rover, suit, transit vehicle, etc.).

The AEMC group discussed mitigation options. Mitigation is not historically part of AEMC, but the group felt that it is an important process to consider. Mitigation would be the set of processes which would reduce the microbial load. For example, cleaning up after a small spill could involve a simple wipe up process. It might be also be necessary to quarantine a spill zone.

6.3.4 Current AEMC Sensitivity Levels

The AEMC Program Element develops technology for monitoring chemistry and microbiology of the crew habitat, as well as process control approaches. It is not only likely that some of the microbial monitoring technologies under AEMC development would be relevant to PP, in fact AEMC leverages the existing NASA PP infrastructure and expertise, as well as the analogous resources in Astrobiology. It is also recognized that the requirements for crew health monitoring are likely to be different in detail from PP requirements.

The current portfolio of AEMC microbial detection technologies ranges from TRL 3, for which feasibility is to be demonstrated, through TRL 5, in which a component is being validated in a relevant environment. There is considerable variation in the time and effort required to apply the various methods, particularly in the different requirements for sample preparation associated with monitoring, including pre-concentration.

The following AEMC microbial monitoring technologies can currently detect at the following levels:

- Deep UV: 1000 molecules of tyrosine at 3 cm. Should convert to single cell in field of view. The capability to speciate is in development.
- Terbium spore detection: 10,000 spores/ml converts to 50 spores/liter of air using existing hardware.

- ATP-based microbial detection ~50 cells.
- AMP-base spore detection about 100 spores.
- LPS-based microbial detection 10 pg endotoxin ~ 30 cells.
- DNA-based microbial detection 10 to 100 cells.
- Quantum Dot Lateral Flow Assay 100 cfu/100ml (cfu = colony forming units).

AEMC is also funding research on the identification of microorganisms by ion mobility spectroscopy, but the work is considered too preliminary to report on its sensitivity.

6.3.5 Contaminants and Pathways

Task: Identify potential contaminants or effects related to monitoring and control hardware systems (if any).

It is first noted that the monitoring technologies themselves can be a source of contamination. For example, using culture-based approaches obviously amplifies the quantity of living matter which then represents a contamination threat. A much smaller threat would come from another technology termed BBICS (Bioluminescent Bioreported Integrated Circuits), which consists of small biochips which contain stabilized microorganisms that have been altered to emit light in the presence of certain chemicals.

The group also recognized that ALS and AEVA equipment are also potential sources, for example biofilms, or a microbial water processor.

The group believes it is necessary to understand the baseline microbial ecosystem due to the presence of humans. This baseline will be present wherever humans go—inside the habitat, outside, within spacesuits and in their vicinity, and similarly with rovers. Detecting a signal in the presence of this possibly substantial baseline may be a challenging signal to noise problem. Performing the tests necessary to establish the baseline will require considerable funding as well as appropriate facilities, some of which may not yet exist.

6.3.6 R&TD Needs

Task: Identify topics that require further research and technology development and discuss development strategies with uncertain PP requirements.

The group recognized the following areas as needing further development:

- Characterization of extravehicular effluents/leaks. This is necessary to establish a baseline understanding of what is released using current technology. The releases may be composed of inorganic chemicals, organic chemicals, intact cells, and cell fragments. The release composition is expected to vary according to the source, which may be EVA suits, habitats, rovers, ISRU, etc. The quantity and composition of the leakage will help refine issues regarding prevention—how much of the leak can be practically attenuated and associated mitigation.

- Characterization of internal environment: habitat, hardware, air, water, etc. What biocomposition is currently found in the internal environment? Is there a correlation to what is leaked, or are there significant differences?
- Sampling/analysis techniques for all the above.
 - Internal (*e.g.*, surfaces, air, water, suit fabric inside and out)
 - External (*e.g.*, surfaces (rocks), atmosphere, soil, effluents/leaks, rover, etc.)
- Sensor network technology encompassing potential leak sources inside and outside.
- Probable biological targets in martian environment. This effort would look at what types of organisms would be likely to exist and survive in the martian environment, based on terrestrial studies. The results would suggest focusing efforts on likely organism types, rather than on the ones which would have no chance of surviving.
- Remediation processes for events; verification of remediation. What methods might be used to clean up an event? Small events might be handled by basically a towel, and some chemicals. Would it then be necessary to verify that the remediation was successful?

6.3.7 Major Obstacles

Task: Identify PP requirements that impose the greatest mission/development costs.

The group identified a number of areas which appear to present imposing challenges.

- Event detection - If it is necessary to detect events such as a sudden significant leak from habitat or suit, the necessary infrastructure to support such detection could be considerable. The group envisioned a large sensor network in landing vicinity.
- Back contamination - What is the nature of the potential biohazard from Mars? The answer would seem necessary in order to define a monitoring system for detection of potential contamination and validation for safe return. The challenge is very large due to level of uncertainty in the understanding of Mars biohazards.
- Remediation technologies - These are methods which would allow for recovery from a contamination release event.
 - Known options are high cost (*e.g.*, using disposables) and only partially effective.
 - *e.g.*, On Mir, Russians used a peroxide quaternary ammonium fungistat wipe. The wipe was not effective on fungus growth in fabric material on walls.
 - Need to consider both forward and backward contamination. Backward contamination is subject to the uncertainties noted above.
 - Need to consider internal/external environments.

- Events which release material to the outside may be able to take advantage of forced exposure to harsh martian environment for reducing forward contamination.
- Mitigation technologies which work well inside the habitat may not be practical outside, and vice versa.
- Small releases may be handled very differently than large releases, although the composition may be similar.
- Quarantine may play a role – there is a need to consider AEMC’s role and requirements during the quarantine of the crew.

6.3.8 Planetary Protection Requirements Definition

Task: Identify PP requirements/topics that require further definition.

The area of greatest uncertainty is clearly the requirement for backward contamination. In addition to this area, the group recognized the following requirements areas as needing further definition:

- Detection/control response time required for AEMC activities/operations
 - Impacts mission operations, mitigation effectiveness
- Commonality and differences between AEMC/PP/Science/Medicine
 - *E.g.*, all may need bacterial sensors, but have different bacterial targets
- PP requirements for human mission
 - Will human missions have same exposed surface requirement as robotic missions? (*e.g.*, Will individual specifications for rovers, habitats, suits, tools, ISRU, etc. be required?)
 - What is the allowable discharge from the suit, airlock, habitat, rover, etc.?

6.3.9 R&TD Rationale

Task: State major findings and assumptions about PP considerations, as you understood them, that will impact your R&TD rationale.

The group recognized that PP currently targets culturable spores only. However, the group also recognized that other targets such as non-culturable spores and cell fragments, could conceivably become PP requirement targets.

6.3.10 Critical Open Issues

Task: Identify critical open issues/uncertainties relative to PP that affect your R&TD (unknowns).

- The AEMC, Medical, PP, and Life Detection Science communities all have overlapping needs and methods, and these must be coordinated through regular communication.

- It will be important to clarify who owns the responsibility for monitoring to PP requirements? AEMC, PP, Science, all three?
- Again it is noted that the back contamination targets/levels are unknown.
- The quantity of biomaterial carried by any crewed mission exceeds the typical current PP requirement by many orders of magnitude. The impact of this situation needs to be understood.

6.3.11 Planetary Protection Requirements Effect on R&TD

Task: Describe the changes to your R&TD program that you believe will be necessary when PP requirements are defined/flowed:

As noted above, the potential impact of PP requirements on monitoring needs can be considerable (in terms of infrastructure) and the current understanding has much uncertainty. It is plausible that the definition of PP requirements will indicate that many years of preparation are necessary to develop the needed monitoring and mitigation approaches. Depending on the extent of PP requirements, there may be considerable impacts on schedule and budget as well.

6.4 REPORT OF PLANETARY PROTECTION (PP) SPECIALIZED BREAKOUT GROUP

6.4.1 Participants of Specialized Breakout Group – Planetary Protection

Lead: Margaret Race

Group Members:

Carlton Allen

Max Coleman

Judy Allton

John Rummel

Jack Barengoltz

Perry Stabekis

Karen Buxbaum

Laurent Sibille

Paul Campbell

6.4.2 Group Charge

The PP Specialized Breakout Group differed from the others in that a primary function of deliberations was to devise a preliminary approach that is capable of guiding ALS, AEVA and AEMC programs regarding system development in relation to PP regulations, as well as provide a framework that establishes a method for subsequent requirements development. The PP Group was charged with addressing the following topics:

- Preliminary recommendations for forward contamination guidelines for human missions to Mars
 - Provide an estimate of the contamination allocable to a single human surface mission (*e.g.*, total microbes released, total biosignature quantity released, size of contaminated area, etc.).

- State assumptions/issues related to this estimate.
- Formulate back contamination guidelines for human missions to Mars
 - Provide an estimate of the allowable probability of Mars organisms reaching Earth (contained in or on a spacecraft) for the return of crew and samples from a single human surface mission.
 - State assumptions/issues related to this estimate.

Specific areas included in the charge:

- Define an approach to address PP Policy development
- Identify the knowledge necessary to establish PP guidelines with respect to ALS and AEVA systems
- Identify monitoring needs for verification of PP policy compliance
- Identify research needs
- Identify PP requirements/topics that require further definition
- Initiate drafts of top-level mission-specific (*e.g.*, 1000 day Mars surface mission) PP policy guidelines, indicating level of certainty and potential future modifications
- Identify and prioritize the most significant threats to PP
- Overall recommendations

6.4.3 Background Information and Starting Assumptions

Current planetary protection requirements address both forward and back contamination with an emphasis on robotic missions, whether one-way or round-trip with sample return. The specific planetary protection requirements for human missions to Mars have not yet been developed and will need further consideration. To date, all deliberations about human missions to Mars have built on lessons learned from the Apollo experiences as well as the findings and recommendations from a limited number of workshops and studies on planetary protection that relate in varying degrees to human issues (*e.g.*, NRC 1992, 1997, 2002a, 2002b; Race *et al.*, 2003). This sub-group likewise built upon this same information during deliberations.

At this time, it is impossible to provide quantitative PP guidelines for mission planners and designers because planetary protection requirements are likely to evolve in the coming years and decades in response to many factors (*e.g.*, rapid changes in scientific information about Mars, advances in technology, improvements in methodologies for assaying cleanliness and reducing bioburden, further advice from the Space Studies Board, revisions in COSPAR PP policies, etc.). Thus, a conceptual approach will be useful in guiding early discussions about AEVA, ALS, AEMC and other aspects of human missions. In developing a conceptual approach that simultaneously addresses planetary protection concerns and considers the science exploration associated with human missions, the subgroup acknowledged that:

- Missions carrying humans to Mars will contaminate the planet. It is therefore critical that every attempt be made to obtain evidence of past and/or present life on Mars well before these missions occur.

- The complex capabilities that human explorers can contribute to the astrobiological exploration of Mars will be realized only if human-associated contamination is controlled and understood.
- Human crew members exploring Mars will inevitably be exposed to martian materials. To the maximum extent practicable, these exposures should occur under controlled conditions.
- Safeguarding the Earth from potential back contamination is the highest planetary protection priority in Mars exploration.

6.4.4 Overview of Preliminary Deliberations

The group developed a tentative conceptual approach consistent with current planetary protection requirements and scientific concerns as follows:

- Human missions to Mars shall not affect or otherwise contaminate “special regions” of Mars³, as defined in the COSPAR Planetary Protection Policy of October 2002.
 - Mission (orbiter, lander, rovers, crew, instruments, and tools) cleanliness requirements shall be determined in such a way as to avoid the inadvertent introduction of Earth organisms or organic molecules into these environments
 - Landing site selection and operational accessibility to scientifically desirable special regions (including prime access by ISRU activities to important subsurface ice or water) shall be directly traded against the microbial or organic cleanliness of human-associated (or robotic) systems supporting the missions.
- Calculations based on this approach will determine the tolerable levels of contamination allowed for specific aspects of any particular human mission. Specific details of the approach are TBD, but will involve working closely with the scientific community to integrate changing information about the martian environment and conditions,⁴ and to evaluate unavoidable levels of human-associated contaminants and their implications as biosignatures that may interfere with scientific investigations and/or the martian environment.

In addition, the sub-group identified the following special issues that relate to the integration of PP concerns throughout mission planning and operations:

1. The first human mission to Mars will face significant levels of risk during the various components of the mission. Planetary protection risks must be among the many risks

³ A “Special Region” is defined as a region within which terrestrial organisms are likely to propagate, OR a region which is interpreted to have a high potential for the existence of extant martian life forms. Given current understanding, this is applied to regions where liquid water is present or may occur. Specific examples include, but are not limited to: subsurface access in an area and to a depth where the presence of liquid water is probable; penetrations into the polar caps; or areas of hydrothermal activity. Note: In considering operational uses of this definition, special regions may include both horizontal and vertical dimensions.

⁴ For example, as a starting point, it may be possible to develop an approach that focuses first on the strictest contaminant standards for special regions based on data about the lower limits of detection of sparse life on Earth. Presumably allowable contaminant levels would be less stringent for operations in and around the landing zone or in areas verified as zones of minimum biological risk.

to be identified and evaluated together - then reduced, mitigated, or eliminated when possible to enable mission success. Close and early coordination is essential among the diverse groups of specialists working on the many phases of mission development.

2. General human factors need to be considered along with planetary protection issues for a human mission to Mars. Physical effects that may lead to debilitation and reduced performance in astronauts could also lead to unintended actions, and in turn, to mishaps with potentially serious planetary protection consequences. Mistakes are much more likely when people are tired, ill, and/or stressed or overly stressed
3. Planetary protection is intimately linked with crew health and safety as well as overall mission success; it must be made a priority and not dismissed or eliminated in any mission phase. A crewmember onboard the mission should be given primary responsibility for the implementation of planetary protection provisions affecting the crew during the mission. In addition, PP information must be emphasized in the development of flight operations plans and medical oversight throughout the mission.

6.4.5 Specific Recommendations

a. Related to Forward Contamination

1. Human mission planning, including landing site selection, base location, and mission objectives, should follow from precursor robotic information and evaluations made at those sites and from information developed from a sample return mission or missions.
2. Definition is needed for a classification system describing and categorizing martian sites of special scientific interest and their level of contamination concern. The classification system shall be developed and employed in future planetary protection protocols, as well as in operational plans for later human missions to Mars.
3. It will not be possible for all human-associated processes and mission operations to be conducted within entirely closed systems. The potential for the long-term consequences of human-associated contamination and the possible interaction of contaminants and environments on Mars require further study.
4. Additional development and design attention are needed to characterize exploration, sampling, and base activities both to assure effective operation and provide the required level of planetary protection assurance.
 - Based on current technologies for robotic missions, controlled, aseptic, subsurface sampling operations will require additional emphasis.

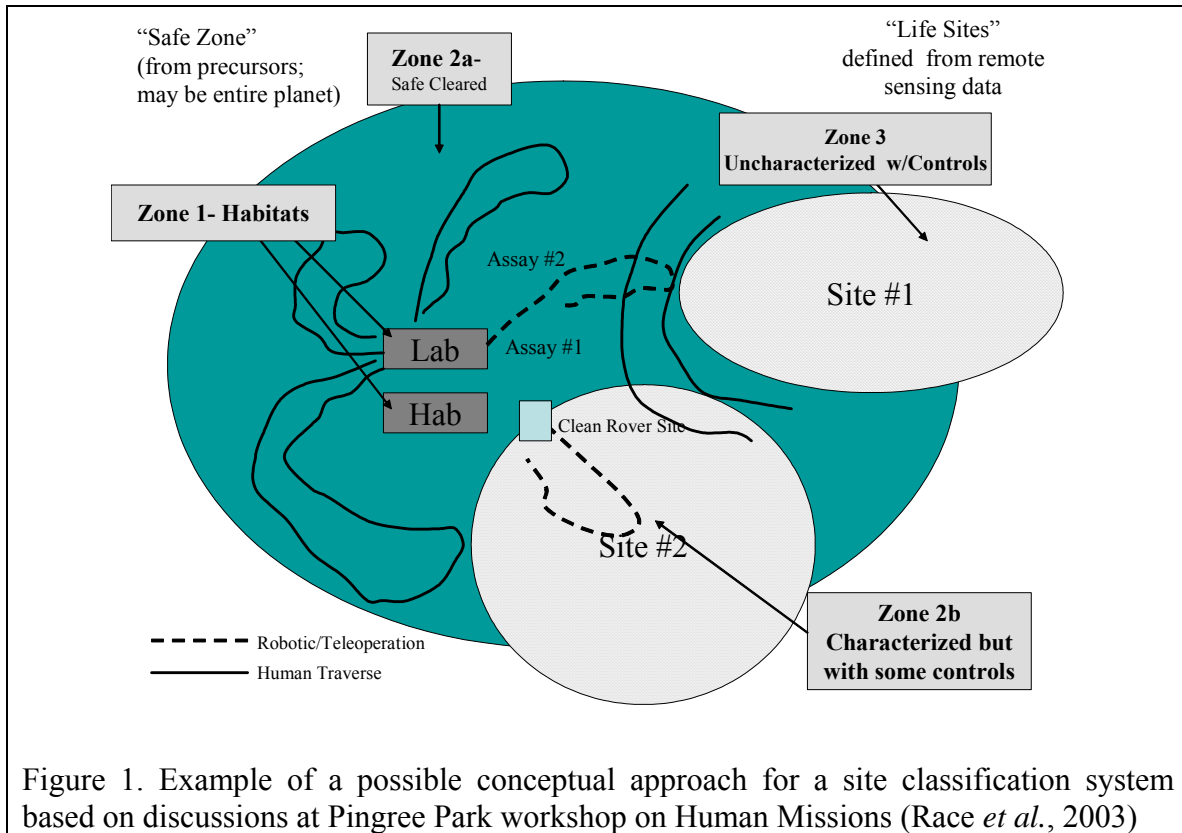
- Other areas needing special attention are: Ingress/egress, suit and EVA designs.⁵
5. Quantitative requirements shall be derived based on protection of special regions, except as follows:
 - No quantitative bioburden requirements should be applied to landing systems or habitats, other than cleanroom assembly (currently Class 100,000, ISO Class 8)⁶
 - Spacecraft, habitats and rovers shall filter material vented as gases (non-condensable), and shall not allow disposal of uncontained solids or fluids.
 - Steps shall be taken to mitigate contamination associated with astronauts involved in EVA operations adjacent to special regions or involved in sampling them
 - Hardware elements involved with accessing special regions be subjected to a sterilizing process either on Earth or on Mars (similar to robotic approach)

b. Related to Back Contamination

1. All operations of an initial human mission to a new site on Mars shall include isolation of humans from directly contacting martian materials until initial testing (either precursor-mission or on-mission robotic testing) can provide a state-of-the-art verification of the landing site as a “zone of minimum biological risk” (provide for the informed consent of the crew).
2. Exploration, sampling, and base activities should be accomplished in a manner to limit inadvertent exposure to the subsurface or to otherwise-untested areas of Mars. A means for allowing controlled access to those areas shall be provided (TBD). Other areas of concern related to inadvertent exposure include repair/maintenance technologies and operations, planning and oversight of activities related to flight and *in situ* operations.
3. The site classification system and a biological plausibility map of the martian surface and subsurface, based on remote sensing data and on-mission testing, shall be employed during any mission to limit potential crew exposure to areas on Mars that might support martian life. (Figure 1 illustrates a possible conceptual approach for such a site classification system.)

⁵ This workshop focused primarily on PP needs related to the first human mission. Other topics of relevance to PP were beyond the scope of this workshop, including impacts of large scale environmental disruption (*e.g.*, building berms, digging trenches), fuel and food production technologies, international PP policy development, and pre-arrival construction and deployment of resources and technologies.

⁶ Classifications (ISO and Federal Standards) are described in:
www.particle.com/whitepapers_met/Cleanroom%20Standards.htm



4. A quarantine capability for both the entire crew and for individual crewmembers shall be provided during the mission, in case uncontrolled contact with a martian life-form occurs. Basic tests of the medical condition of the crew and their potential response to pathogens or adventitious microbes shall be defined, provided, and employed regularly on the mission. It is essential that medical oversight and quarantine planning be informed by planetary protection information and guidelines.
5. A quarantine capability and appropriate medical testing shall be provided for the crew upon return to the Earth (or Moon or Earth-orbit) and implemented in conjunction with a health stabilization program.
6. Samples returned by the crew from uncontrolled or otherwise-untested areas of Mars shall be considered as potentially hazardous, and shall not be released from containment until a series of tests determines that they do not present a biohazard.

6.4.6 R&TD Needs

1. Describe the potential impacts on the near-field martian environment of human support activities expected in the operation of a human-occupied martian base, *e.g.*, breathing oxygen, food supply, waste management, etc., to determine the zone of contamination associated with a human landing, and the plausible limits of zones of no-contamination that can be preserved nearby.

2. Define the spatial dispersion of dust and human-associated contaminants on Mars by wind and other means.
3. Determine the survivability of a range of Earth organisms and their component molecules in the ambient Mars environment, and in the conditions of the martian near-subsurface.
4. Examine future ALS designs and concepts with respect to planetary protection needs, especially those related to organic and microbial contamination, to assess the potential effects of human activities in pressurized habitats and human-carrying rovers.
5. Examine future AEVA designs (thermal control, gas control, material leakage) with respect to planetary protection needs, especially with respect to organic and microbial contamination, to assess the potential effects of human activities on the martian surface away from pressurized habitats and human-carrying rovers.
6. Develop AEMC technology required for life detection and potential pathogen detection, with a focus on sensitivity and specificity of tests needed to identify potential microbes of unknown origin.
7. Determine how to conduct human-associated robotic operations on Mars to be consistent with planetary protection concerns, both those deployed independently during precursor missions and in conjunction with human landings during later missions.

6.4.7 Conclusions

Although there is an absence of explicit PP policies and requirements for human missions to Mars at present, it is possible to outline a conceptual approach and provide preliminary guidelines for planners and designers of AEVA, ALS, and AEMC activities. Refinement of the approach and development of more specific guidelines will likely occur over time in response to information from R&TD activities coupled with findings from the many precursor robotic missions outlined in the Exploration Roadmap (see Figure 2). PP requirements for human missions will undoubtedly be very different than those used during Apollo missions. Clearly, early and regular coordination between the PP, scientific, planning, engineering, operations and medical communities is needed to develop workable and effective designs for human operations on Mars. Coordination will bring numerous mutual advantages to the various programs such as identifying common needs for new technologies (*e.g.*, among planetary science exploration, human mission operations, and PP). Finally, long duration operations on the Moon may provide a relevant test-bed for many mission technologies. Mission planners must address PP technology on the Moon in ways that feed forward to martian exploration, even though the actual PP levels required on the Moon are considerably less stringent than those for Mars. Current concerns about biological potential and life detection on Mars suggest that technologies and operations related to planetary protection are likely to need special

attention. In planning the long term design and operations strategies, it will be important to avoid going down two distinct and expensive technology pathways—one for the Moon and the other for Mars.

Exploration PP Roadmap

Current Standards

- Moon has no basic PP requirements (but a rich history)
- Mars requirements driven by Viking as of 1992—soon to be updated for Odyssey, MERs, MGS
- Human-mission requirements to be driven by MSL, AFL, Mars Sample Return, and policy decisions.

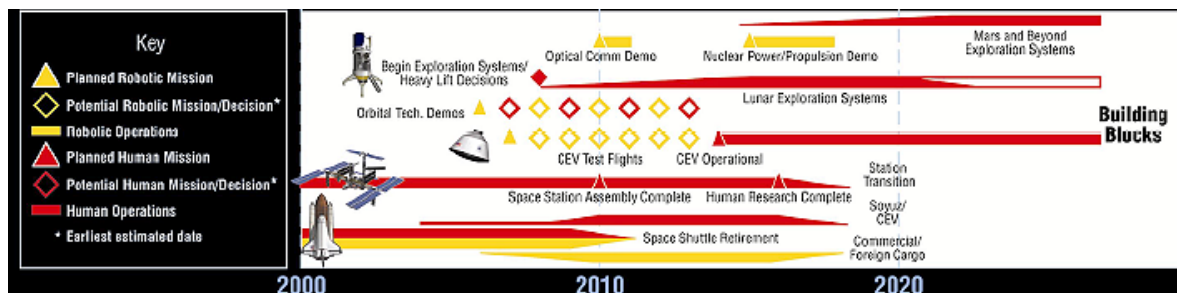
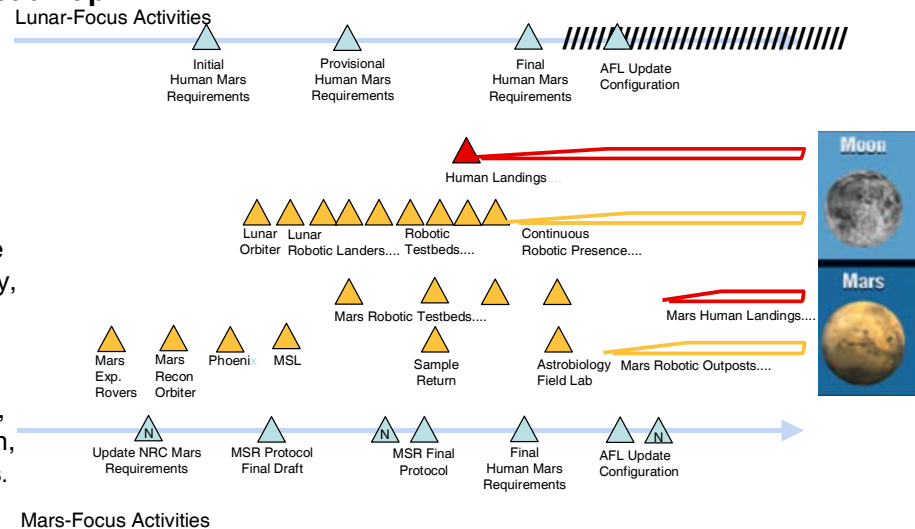


Figure 2: Exploration PP Roadmap showing potential linkages and schedules for development of Mars human mission PP requirements based on Mars robotic precursor missions, future lunar missions, and Mars focused activities.

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APPENDIX A – ACRONYM LIST

AEMC – Advanced Environmental Monitoring and Control

AEVA – Advanced Extravehicular Activity

ALS – Advanced Life Support

CEV – Crew Exploration Vehicle

CFU – Colony Forming Unit: a measure of microbial growth in lab assays

CO₂ – Carbon Dioxide

ELS – Exploration Life Support

EMU – Extravehicular Mobility Unit

ESMD – Exploration Systems Mission Directorate

ET – Extraterrestrial

EVA – Extravehicular Activity

HACCP - Hazard Analysis and Critical Control Point

ISRU – *In-Situ* Resource Utilization

JPL – Jet Propulsion Laboratory

LSH – Life Support and Habitation

MEPAG - Mars Exploration Program Assessment Group

PLSS – Portable Life Support System

PP – Planetary Protection

PSIA – Pounds per Square Inch Absolute

SCCM - Standard Cubic Centimeter per Minute

TRL - Technology Readiness Level

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APPENDIX C – WORKSHOP AGENDA

Wednesday, April 27, 2005

8:00 – 8:05	Welcome and Objectives of Workshop – Dr. Jitendra A. Joshi
8:05 – 8:15	Vision and Charter - Dr. Carl Walz and Dr. John D. Rummel
8:15 – 8:30	Workshop Structure and Implementation – Dr. Jitendra Joshi
8:30 – 9:10	Advanced Life Support – Dr. Daniel J. Barta
9:10 – 9:50	Advanced Extravehicular Activity – Dr. Lara Kearney
9:50 – 10:30	Advanced Environmental Monitoring and Control – Dr. Darrell Jan
10:30 – 10:45	Break
10:45 – 11:25	Planetary Protection Policy and its Development – Dr. John D. Rummel
11:25 – 12:00	Planetary Protection Implementation on Robotic Missions – Dr. Karen Buxbaum
12:00 – 1:00	Lunch
1:00 – 1:40	Planetary Protection and Humans on Mars – Report of the First Workshop – Dr. Margaret Race
1:40 – 1:50	Charge to groups - Assignment to initial breakout groups (2)
1:50 – 3:00	Begin general breakout groups – Identification of overall issues
3:00 – 3:15	Break
3:15 – 4:30	Continue Breakout Group Discussions
4:30 – 5:00	Presentation Preparation
5:00	End of Day

Thursday, April 28, 2005

8:00 – 9:00	Initial general presentations and discussion – Groups 1 & 2
9:00 -10:30	Specialized breakout groups begin
10:30 – 10:45	Break
10:45 – 12:00	Specialized breakout groups continue
12:00 - 1:00	Lunch
1:00 - 3:00	Specialized breakout groups continue
3:00 - 3:15	Break
3:15 - 5:30	Specialized breakout groups continue
5:30	End of Day

Friday, April 29, 2005

8:00 - 9:30	Specialized Breakout Groups prepare final presentations
9:30 - 9:50	ALS Group presentation
9:50 - 10:10	AEVA Group presentation
10:10 – 10:30	AEMC Group presentation
10:30 – 10:45	Break

10:45 – 11:15	Planetary Protection Group presentation
11:15 – 11:45	Group Discussion – Identification of future needs
11:45 – 12:00	Conclusions
12:00	End of Workshop

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13. SUPPLEMENTARY NOTES Point of Contact: John W. Fisher, NASA Ames Research Center, MS239-15, Moffett Field, CA 94035-1000					
14. ABSTRACT A workshop entitled "Life Support and Habitation and Planetary Protection Workshop" was held in Houston, Texas on April 27-29, 2005 to facilitate the development of planetary protection guidelines for future human Mars exploration missions and to identify the potential effects of these guidelines on the design and selection of related human life support, extravehicular activity and monitoring and control systems. This report provides a summary of the workshop organization, starting assumptions, working group results and recommendations. Specific result topics include the identification of research and technology development gaps, potential forward and back contaminants and pathways, mitigation alternatives, and planetary protection requirements definition needs. Participants concluded that planetary protection and science-based requirements potentially affect system design, technology trade options, development costs and mission architecture. Therefore early and regular coordination between the planetary protection, scientific, planning, engineering, operations and medical communities is needed to develop workable and effective designs for human exploration of Mars.					
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